
Charles Bell

ANIMAL MECHANICS

BY

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AND

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PREFACE

THESE Papers are selections from the writings of Sir Charles Bell [1774–1842] and Dr. Jeffries Wyman [1814–1874]. They are memorable examples of careful observation, sound reasoning, and clear description of the objects of which they treat.

They are reprinted as worthy the serious consideration of all those in preparation for their life-pursuits.

MORRILL WYMAN.

CAMBRIDGE, 1902.

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ANIMAL MECHANICS

OR

PROOFS OF DESIGN IN THE ANIMAL FRAME

THE PERFECTION OF DESIGN IN THE BONES OF THE HEAD, SPINE, AND CHEST, SHOWN BY COMPARISON WITH ARCHITECTURAL AND MECHANICAL CONTRIVANCES

BY

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ANIMAL MECHANICS

INTRODUCTION

To prepare us for perceiving design in the various internal structures of an animal body, we must, first of all, know that perfect security against accidents is not consistent with the scheme of nature. A liability to pain and injury only proves how entirely the human body is formed with reference to the mind; since, without the continued call to exertion, which danger and the uncertainty of life infer, the development of our faculties would be imperfect, and the mind would remain, as it were, uneducated.

The contrivances (as we should say of things of art) for protecting the vital organs are not absolute securities against accidents; but they afford protection in that exact measure or degree calculated to resist the shocks and pressure to which we are exposed in the common circumstances of life. A man can walk, run, leap, and swim, because the texture of his frame, the strength and power of his limbs, and the specific gravity of his body are in relation with all around him. But,

were the atmosphere lighter, the earth larger, or its attraction more; were he, in short, an inhabitant of another planet, there would be no correspondence between the strength, gravity, and muscular power of his body, and the elements around him, and the balance in the chances of life would be destroyed.

Without such considerations the reader would fall into the mistake that weakness and liability to fracture imply imperfection in the frame of the body, whereas a deeper contemplation of the subject will convince him of the incomparable perfection both of the plan and of the execution. The body is intended to be subject to derangement and accident, and to become, in the course of life, more and more fragile, until, by some failure in the framework or vital actions, life terminates.

And this leads us to reflect on the best means of informing ourselves of the intention or design shown in this fabric. Can there be any better mode of raising our admiration than by comparing it with things of human invention? It must be allowed that we shall not find a perfect analogy. If we compare it with the forms of architecture — the house or the bridge are not built for motion, but for solidity and firmness, on the principle of gravitation. The ship rests in equilibrium prepared for passive motion, and the contrivances of the ship-builders are for resisting

an external force; whilst in the animal body we perceive securities against the gravitation of the parts, provisions to withstand shocks and injuries from without, at the same time that the framework is also calculated to sustain an internal impulse from the muscular force which moves the bones as levers, or, like a hydraulic engine, propels the fluids through the body.

As in things artificially contrived, lightness and motion are balanced against solidity and weight, it is the same in the animal body. A house is built on a foundation immovable, and the slightest shift of the ground, followed by the ruin of the house, brings no discredit on the builder; for he proceeds on the certainty of strength from gravitation on a fixed foundation. But a ship is built with reference to motion, to receive an impulse from the wind, and to move through the water. In comparison with the fabric founded on the fixed and solid ground, it becomes subjected to new influences, and in proportion as it is fitted to move rapidly in a light breeze, it is exposed to founder in the storm. A log of wood, or a Dutch dogger almost as solid as a log, is comparatively safe in the trough of the sea during a storm, when a bark, slightly built and fitted for lighter breezes, would be shaken to pieces; that is to say, the masts and rigging of a ship (the provisions for its motion) may become

the source of weakness, and, perhaps, of destruction; and safety is thus voluntarily sacrificed in part to obtain another property of motion.

So in the animal body: sometimes we see the safety of parts provided for by strength calculated for inert resistance; but when made for motion, when light and easily influenced, they become proportionally weak and exposed, unless some other principle be admitted, and a different kind of security substituted for that of weight and solidity: still a certain insecurity arises from this delicacy of structure.

We shall afterwards have occasion to show that there is always a balance between the power of exertion and the capability of resistance in the living body. A horse or a deer receives a shock in alighting from a leap; but still the inert power of resisting that shock bears a relation to the muscular power with which they spring. And so it is in a man: the elasticity of his limbs is always accommodated to his activity; but it is obvious, that in a fall, the shock, which the lower extremities are calculated to resist, may come on the upper extremity, which, from being adapted for extensive and rapid motion, is incapable of sustaining the impulse, and the bones are broken or displaced.

The analogy between the structure of the human body and the works of human contrivance,

which we have to bring in illustration of the designs of nature, is, therefore, not perfect, since sometimes the material is different, sometimes the end to be attained is not precisely the same; and, above all, in the animal body a double object is often secured by the structure or framework, which cannot be accomplished by mere human ingenuity, and of which, therefore, we can offer no illustration strictly correct.

However ingenious our contrivances may be, they are not only limited, but they present a sameness which becomes tiresome. Nature, on the contrary, gives us the same objects of interest, or images of beauty, with such variety, that they lose nothing of their influence and their attraction by repetition.

If the reader has an imperfect notion of design and providence from a too careless survey of external nature, and the consequent languor of his reflections, we hope that the mere novelty of the instances we are about to place before him may carry conviction to his mind; for we are to draw from nature still, but in a field which has been left strangely neglected, though the nearest to us of all, and of all the most fruitful.

Men proceed in a slow course of advancement in architectural, or mechanical, or optical sciences; and when an improvement is made, it is found that there are all along examples of it in

the animal body, which ought to have been marked before, and which might have suggested to us the improvement. It is surprising that this view of the subject has seldom, if ever, been taken seriously, and never pursued. Is the human body formed by an all-perfect Architect, or is it not? And, if the question be answered in the affirmative, does it not approach to something like infatuation that, possessing such perfect models as we have in the anatomy of the body, we yet have been so prone to neglect them? We undertake to prove that the foundation of the Eddystone lighthouse, the perfection of human architecture and ingenuity, is not formed on principles so correct as those which have directed the arrangement of the bones of the foot; that the most perfect pillar or kingpost is not adjusted with the accuracy of the hollow bones which support our weight; that the insertion of a ship's mast into the hull is a clumsy contrivance compared with the connections of the human spine and pelvis; and that the tendons are composed in a manner superior to the last patent cables of Huddart, or the yet more recently improved chain-cables of Bloxam.

Let us assume that the head is the noblest part; and let us examine the carpentry and architectural contrivances exhibited there.

But, before we give ourselves up to the interest of this subject, it will gratify us to express our conviction that the perfection of the plan of animal bodies, the demonstration of contrivance and adaptation, but more than these, the proof of the continual operation of the power which originally created the system, are evinced in the property of life, — in the adjustment of the various sensibilities, — in the fine order of the moving parts of the body, — in the circulation of living blood, — in the continual death of particles and their removal from the frame, — in the permanence of the individual whilst every material particle of his frame is a thousand times[1] changed in the progress of his life. But this is altogether a distinct inquiry, and we are deterred from touching upon it, not more from knowing that our readers are not initiated into it, than from the depth and very great difficulty of the subject.

[1] The old philosophers gave out that the human body was seven times changed during the natural life. Modern discoveries have shown that the hardest material of the frame is changing continually ; that is, every instant of time, from birth to death.

CHAPTER I

ARCHITECTURE OF THE SKULL

It requires no disquisition to prove that the brain is the most essential organ of the animal system, and being so, we may presume that it must be especially protected. We are now to inquire how this main object is attained.

We must first understand that the brain may be hurt, not only by sharp bodies touching and entering it, but by a blow upon the head which shall vibrate through it, without the instrument piercing the skull. Indeed, a blow upon a man's head, by a body which shall cause a vibration through the substance of the brain, may more effectually deprive him of sense and motion than if an axe or a sword penetrated into the substance of the brain itself.

Supposing that a man's ingenuity were to be exercised in contriving a protection to the brain, he must perceive that if the case were soft, it would be too easily pierced; that if it were of a glassy nature, it would be chipped and cracked; that if it were of a substance like metal, it would ring and vibrate, and communicate the concussion to the brain.

Further thoughts might suggest that, whilst the case should be made firm to resist a sharp point, the vibrations of that circular case might be prevented by lining it with a softer material; no bell would vibrate with such an incumbrance; the sound would be stopped like the ringing of a glass by the touch of a finger.

If a soldier's head be covered with a steel cap, the blow of a sword which does not penetrate will yet bring him to the ground by the percussion which extends to the brain; therefore, the helmet is lined with leather and covered with hair; for, although the hair is made an ornament, it is an essential part of the protection: we may see it in the head-piece of the Roman soldier, where all useless ornament, being despised as frivolous, was avoided as cumbrous.

We now perceive why the skull consists of two plates of bone, — one external, which is fibrous and tough, and one internal, dense to such a degree that the anatomist calls it *tabula vitrea* (the glassy table).

Nobody can suppose this to be accidental. It has just been stated that the brain may be injured in two ways: a stone or a hammer may break the skull, and the depressed part of the bone injure the brain; whilst, on the other hand, a mallet struck upon the head will, without penetrating, effectually deprive the brain of its functions, by

causing a vibration which runs round the skull and extends to every portion of its contents.

Were the skull, in its perfect or mature state, softer than it is, it would be like the skull of a child; were it harder than we find it is, it would be like that of an old man. In other words, as in the former it would be too easily pierced, so, in the latter, it would vibrate too sharply and produce concussion. The skull of an infant is a single layer of elastic bone; on the approach to manhood it separates into two tables; and in old age it again becomes consolidated. During the active years of man's life the skull is perfect: it then consists of two layers, united by a softer substance; the inner layer is brittle as glass, and calculated to resist anything penetrating; the outer table is tough, to give consistence, and to stifle the vibration which would take place if the whole texture were uniform and like the inner table.

The alteration in the substance of the bones, and more particularly in the skull, is marvellously ordered to follow the changes in the mind of the creature, from the heedlessness of childhood to the caution of age, and even the helplessness of superannuation.

The skull is soft and yielding at birth; during childhood it is elastic, and little liable to injury from concussion; and during youth, and up to the period of maturity, the parts which come in

contact with the ground are thicker, whilst the shock is dispersed towards the sutures (the seams or joinings of the pieces), which are still loose. But when, with advancing years, something tells us to give up feats of activity, and falls are less frequent, the bones lose that nature which would render concussion harmless, and at length the timidity of age teaches man that his structure is no longer adapted to active life.

We must understand the necessity of the double layer of the skull, in order to comprehend another very curious contrivance. The sutures are the lines of union of the several bones which form the *cranium*,[1] and surround and protect the brain. These lines of union are called *sutures* (from the Latin word for *sewing*), because they resemble seams. If a workman were to inspect the joining of two of the bones of the cranium, he would admire the minute dovetailing by which one portion of the bone is inserted into, and surrounded by, the other, whilst that other pushes its processes or juttings out between those of the first in the same manner, and the fibres of the two bones are thus interlaced, as you might interlace your fingers. But when you look to the internal

[1] *Cranium*, from a Greek word signifying a helmet. The cranium is the division of the skull appropriated to the protection of the brain; it consists of six bones — the *frontal* (or forehead); two *parietal* (walls or side bones); the *occipital* (back of the head); and two *temporal* (or temple) bones.

surface, you see nothing of this kind; the bones are here laid simply in contact, and this line by anatomists is called *harmonia*, or harmony: architects use the same term to imply the joining by masonry. Whilst the anatomists are thus curious in names, it is provoking to find them negligent of things more interesting. Having overlooked the reason of the difference in the tables of bone, they are consequently blind to the purpose of this difference of the outward and inward part of a suture.

Suppose a carpenter employed upon his own material, he would join a box with minute and regular indentations by dovetailing, because he knows that the material on which he works, from its softness and toughness, admits of such adjustment of its edges. The processes of the bone shoot into the opposite cavity with an exact resemblance to the foxtail wedge of the carpenter — a kind of tenon and mortise when the pieces are small.

But if a workman in glass or marble were to inclose some precious thing, he would smooth the surfaces and unite them by cement, because, even if he could succeed in indenting the line of union, he knows that his material would chip off on the slightest vibration. The edges of the marble cylinders which form a column are, for the same reason, not permitted to come in contact; thin

plates of lead are interposed to prevent the edges, technically termed *arrises*, from chipping off or splitting.

Now apply this principle to the skull. The outer softer tough table, which is like wood, is indented and dovetailed; the inner glassy table has its edges simply laid in contact. It is mortifying to see a course of bad reasoning obscure this beautiful subject. They say that the bone growing from its centre, and diverging, shoots its fibres betwixt those which come in an opposite direction; thus making one of the most curious provisions of nature a thing of accident. Is it not enough to ask such reasoners, why there is not a suture on the inside as well as on the out?

The junction of the bones of the head generally being thus exact, and like the most finished piece of cabinet work, let us next inquire, whether there be design or contrivance shown in the manner in which each bone is placed upon another.

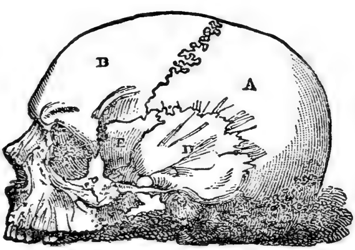


FIG. 1.

A. The *parietal bone*. B. The *frontal* bone. C. The *occipital* bone. D. The *temporal* bone. E. The *sphenoid* bone.

When we look upon the side of the skull thus, the temporal suture betwixt the bones A and D is formed in

a peculiar manner; the lower, or temporal, bone laps over the superior, or parietal, bone. This, too, has been misunderstood: that is to say, the plan of the building of the bones of the head has not been considered; and this joining, called the squamous[1] suture, which is a species of scarfing, has been supposed a mere consequence of the pressure of the muscle which moves the jaw.

Dr. Monro says, "The manner how I imagine this sort of suture is formed at these places, is, that by the action of the strong temporal muscles on one side, and by the pressure of the brain on the other, the bones are made so thin that they have not large enough surfaces opposed to each other to stop the extension of their fibres in length, and thus to cause the common serrated appearance of sutures; but the narrow edge of the one bone slides over the other."

The very name of the bones might suggest a better explanation. The *ossa parietalia*[2] are the two large bones in a regular square, serving as walls to the interior or room of the head, where the brain is lodged. — *See* A *in the foregoing figure.*

Did the reader ever notice how the walls of a house are assisted when thin and overburdened with a roof?

[1] From *squama*, the Latin for a *scale*, the thin edges lying over each other like the scales of a fish.

[2] From the Latin word *paries*, a wall.

The *wall plate* is a portion of timber built into the wall, to which a transverse or tie-beam is attached by carpentry. This *cogging*, as it is termed, keeps the wall in the perpendicular, and prevents any lateral pressure of the roof.[1] We sometimes see a more clumsy contrivance, a clasp, or a round plate of iron, upon the side of a wall; this has a screw going into the ends of a cross-beam, and by embracing a large portion of the brick-work, it holds the wall from shifting at this point. Or take the instance of a roof supported on inclined rafters, A B: —

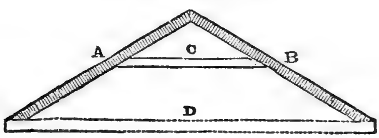


FIG. 2.

Were they thus, without further security, placed upon the walls, the weight would tend to spur or press out the walls, which must be strong and heavy to support the roof; therefore, the skeleton of the roof is made into a *truss* (for so the whole joined carpentry is called). The upper cross-beam, marked by the dotted lines C, is a collar-beam, connecting the rafters of the roof, and stiffening

[1] In the second Treatise on Heat, the reader will find an account of the manner in which the expansion of iron by heat, and its subsequent contraction on cooling, is used in order to cog great buildings.

them, and making the weight bear perpendicularly upon the walls. When the transverse beam joins the extremities of the rafters, as indicated by the lower outline D, it is called a *tie-beam*, and is more powerful still in preventing the rafters from pushing out the walls.

Now when a man bears a burden upon his head, the pressure, or horizontal push, comes upon the lower part of the *parietal bones*, and if they had not a tie-beam, they would, in fact, be spurred out, and the bones of the head be crushed down. But the temporal bone D, and still more, the sphenoid bone E, by running across the base of the skull, and having their edges lapping over the lower part of the great walls, or the parietal bones, lock in the walls as if they had iron plates, and answer the purpose of the tie-beam in the roof, or the iron plate in the walls. But the connection is at the same time so secure, that these bones act equally as a *straining*-piece, that is, as a piece of timber, preventing the tendency of the sides *of the skull* to each other.

It may be said, that the skull is not so much like the wall of a house as like the arch of a bridge: let us then consider it in this light.

We have here the two parietal bones, separated and resting against each other, so as to form an arch. In the centering, which is the wooden frame for supporting a stone arch while building,

there are some principles that are applicable to the head.

We see that the arch formed by the two parietal bones is not a perfect semicircle: there is a projection at the centre of each bone; the bone is more convex, and thicker at this part.

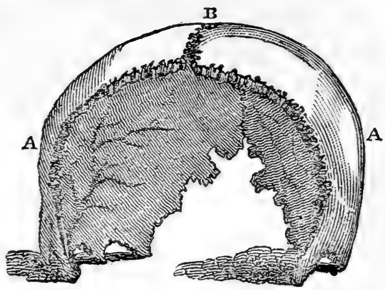


FIG. 3.

The cause assigned for this is, that it is the point from which ossification begins, and where it is, therefore, most perfect. But this is to admit a dangerous principle, that the forms of the bones are matter of chance: and thence we are left without a motive for study, and make no endeavor to comprehend the uses of parts. We find that all the parts which are most exposed to injury are thus strengthened, — the centre of the forehead, the projecting point of the skull behind, and the lateral centres of the parietal and frontal bones. The parts of the head which would strike upon the ground when a man falls are the strongest, and the projecting arch of the parietal bone is a protection to the weaker temporal bone.

If we compare the skull to the *centering*, where a bridge is to be built over a navigable river, and

consequently where the space must be free in the middle, we find that the scientific workmen are careful, by a transverse beam, to protect the points where the principal thrust will be made in carrying up the masonry: this beam does not act as a tie-beam, but as a straining-piece, preventing the arch from being crushed in at this point.

The necessity of strengthening certain points is well exhibited in the carpentry of roofs. In

FIG. 4.

this figure it is clear, that the points A A will receive the pressure of the roof, and if the joining of the puncheons [1] and rafters be not secure, it will sink down in the form of the dotted line. The workmen would apply braces at these angles to strengthen them.

In the arch, and at the corresponding points of the parietal bones, the object is attained by strengthening these points by increase of their convexity and thickness; and where the workman would support the angles by braces, there are ridges of bone in the calvaria [2] or roof of the skull.

If a stone arch fall, it must give way in two places at the same time; the centre cannot sink

[1] The puncheons are the upright lateral pieces, the rafters are the timbers which lie oblique, and join the puncheons at A A.

[2] From the Latin *calva*, or *calvaria*, *a helmet*.

unless that part of the arch which springs from the pier yields; and in all arches, from the imperfect Roman arch to that built upon modern principles, the aim of the architect is to give security to this point.

In the Roman bridges still entire the arch rises high, with little inclination at the lower part; and in bridges of a more modern date we see a mass of masonry erected on the pier, sometimes assuming the form of ornament, sometimes of a tower or gateway, but obviously intended at the same time, by the perpendicular load, to resist the horizontal pressure of the arch. If this be omitted in more modern buildings, it is supplied by a finer art, which gives security to the masonry of the pier (to borrow the terms of anatomy), by its internal structure.

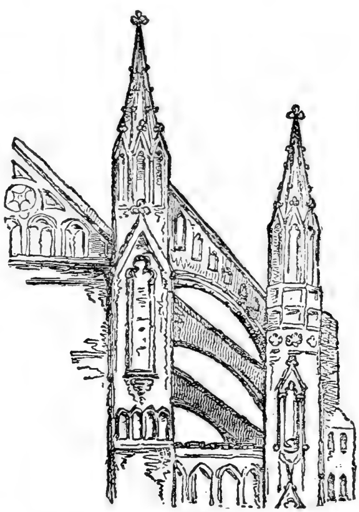


Fig. 5.

In what is termed Gothic Architecture, we see a flying buttress, springing from the outer wall, carried over the roof of the aisle, and abutting against the wall of the

upper part, or *clerestory*. From the upright part of this masonry a pinnacle is raised, which at first appears to be a mere ornament, but which is necessary, by its perpendicular weight, to counteract the horizontal thrust of the arch.

By all this we see, that if the skull is to be considered as an arch, and the parietal bones as forming that arch, they must be secured at the temporal and sphenoid[1] bones, the points from which they spring. And, in point of fact, where is it that the skull yields when a man falls, so as to strike the top of his head upon the ground? — in the temples. And yet the joinings are so secure that the extremity of the bone does not start from its connections. It must be fractured before it is spurred out, and in that case only does the upper part of the arch yield.

But the best illustration of the form of the head is the dome.

A dome is a vault rising from a circular or elliptical base; and the human skull is, in fact, an elliptical surmounted dome, which latter term means that the dome is higher than the radius of its base. Taking this matter historically, we should presume that the dome was the most diffi-

[1] In the Greek, *sphenoïd*, — in the Latin, *cuneiform*, — like a wedge, because it is wedged among the other bones of the head; but these processes, called wedges, are more like dovetails, which enter into the irregularities of the bones, and hold them locked.

cult piece of architecture, since the first dome erected appears to have been at Rome, in the reign of Augustus — the Pantheon, which is still entire. The dome of St. Sophia, in Constantinople, built in the time of the Emperor Justinian, fell three times during its erection: and the dome of the Cathedral of Florence stood unfinished 120 years for want of an architect. Yet we may, in one sense, say that every builder who tried it, as well as every laborer employed, had the most perfect model in his own head. It is obvious enough that the weight of the upper part of the dome must disengage the stones from each other which form the lower circle, and tend to break up their joinings, and consequently to press or thrust outwards the circular wall on which it rests. No walls can support the weight, or rather, the lateral thrust, unless each stone of the dome be soldered to another, or the whole hooped together and girded. The dome of St. Paul's has a very strong double iron chain, linked together, at the bottom of the cone; and several other lesser chains between that and the cupola, which may be seen in the section of St. Paul's engraved by Hooker.

The bones of the head are securely bound together, so that the anatomist finds, when everything is gone, save the bone itself, and there is neither muscle, ligament, nor membrane of any

kind, to connect the bones, they are, still, securely joined, and it requires his art to burst them asunder; and for this purpose he must employ a force which shall produce a uniform pressure from the centre outwards; and all the sutures must receive the pressure at one time and equally, or they will not give way. And now is the time to observe another circumstance, which calls for our admiration. So little of accident is there in the joining of the bones, that the edge of a bone at the suture lies over the adjoining bone at one part and under it at another, which, with the dovetailing of the suture, as before described, holds each bone in its place firmly attached; and it is this which gives security to the dome of the cranium.

If we look at the skull in front, we may consider the orbits of the eye as crypts under the greater building. And these under-arches are groined, that is to say, there are strong arched spines of bone, which give strength sufficient to permit the interstices of the groinings, if I may so term them, to be very thin. Betwixt the eye and the brain, the bone is as thin as parchment; but if the anterior part of the skull had to rest on this, the foundation would be insufficient. This is the purpose of the strong ridge of bone which runs up like a buttress from the temple to the lateral part of the frontal bone, whilst the arch forming the upper part of the orbit is very strong:

and these ridges of bone, when the skull is formed with what we call a due regard to security, give an extension to the forehead.[1]

In concluding this survey of the architecture of the head, let us suppose it so expanded that we could look upon it from within. In looking up to the vault, we should at once perceive the application of the *groin* in masonry; for the groin is that projection in the vault which results from the intersection of two arches running in different directions. One rib or groin extends from the centre of the frontal bone to the most projecting part of the occipital foramen, or opening on the back of the head; the other rib crosses it from side to side of the occipital bone. The point of intersection of these two groins is the thickest and strongest part of the skull, and it is the most exposed, since it is the part of the head which would strike upon the ground when a man falls backwards.

What is termed the base of the skull is strengthened, if we may so express it, on the same principle: it is like a cylinder groin, where the rib of an arch does not terminate upon a buttress or pilaster, but is continued round in the completion

[1] Although they are solid arches connected with the building of the cranium, and bear no relation to the surfaces of the brain, the early craniologists would have persuaded us that their forms correspond with the surfaces of the brain, and indicate particular capacities or talents.

of the circle. The base of the skull is irregular, and in many places thin and weak, but these arched spines or ribs give it strength to bear those shocks to which it is of course liable at the joining of the skull with the spine.

CHAPTER II

MECHANISM OF THE SPINE

THE brain-case is thus a perfect whole, secure on all sides, and strengthened where the exposure to injury is the greatest. We shall see, in the column which sustains it, equal provision for the security of the brain; and, what is most admirable, there is an entirely different principle introduced here; for whereas in the head, the whole aim is firmness in the joinings of the bones, in the spine which supports the head, the object to be attained is mobility or pliancy. In the head, each bone is firmly secured to another; in the spine, the bones are not permitted to touch: there is interposed a soft and elastic material, which takes off the jar that would result from the contact of the bones. We shall consider this subject a little more in detail.

The spinal column, as it is called, serves three purposes: it is the great bond of union betwixt all the parts of the skeleton; it forms a tube for the lodgment of the spinal marrow, a part of the nervous system as important to life as the brain itself; and lastly, it is a column to sustain the head.

We now see the importance of the spine, and we shall next explain how the various offices are provided for.

If the protection of the spinal marrow had been the only object of this structure, it is natural to infer that it would have been a strong and unyielding tube of bone; but, as it must yield to the inflections of the body, it cannot be constituted in so strict an analogy with the skull. It must, therefore, bend; but it must have no abrupt or considerable bending at one part; for the spinal marrow within would in this way suffer.

By this consideration we perceive why there are twenty-four bones in the spine, each bending a little; each articulated or making a joint with its fellows; all yielding in a slight degree, and, consequently, permitting in the whole spine that flexibility necessary to the motions of the body. It is next to be observed that, whilst the spine by this provision moves in every direction, it gains a property which it belongs more to our present purpose to understand. The bones of the spine are called vertebræ; at each interstice between these bones, there is a peculiar gristly substance, which is squeezed out from betwixt the bones, and, therefore, permits them to approach and play a little in the motions of the body. This gristly substance is inclosed in an elastic binding or membrane of great strength, which passes from

the edge or border of one vertebra to the border of the one next it. When a weight is upon the body, the soft gristle is pressed out, and the membrane yields: the moment the weight is removed, the membranes recoil by their elasticity, the gristle is pressed into its place, and the bones resume their position.

We can readily understand how great the influence of these twenty-four joinings must be in giving elasticity to the whole column; and how much this must tend to the protection of the brain. Were it not for this interposition of elastic material, every motion of the body would produce a jar to the delicate texture of the brain, and we should suffer almost as much in alighting on our feet as in falling on our head. It is, as we have already remarked, necessary to interpose thin plates of lead or slate between the different pieces of a column to prevent the edges (technically called arrises) of the cylinders from coming in contact, as they would, in that case, chip or split off.

But there is another very curious provision for the protection of the brain: we mean the curved form of the spine. If a steel spring, perfectly straight, be pressed betwixt the hands from its extremities, it will resist, notwithstanding its elasticity, and when it does give way, it will be with a jerk.

Such would be the effect on the spine if it stood upright, one bone perpendicular to another; for then the weight would bear equally; the spine would yield neither to one side nor to the other; and, consequently, there would be a resistance from the pressure on all sides being balanced. We therefore see the great advantage resulting from the human spine being in the form of an italic *s*. It is prepared to yield in the direction of its curves; the pressure is of necessity more upon one side of the column than on the other; and its elasticity is immediately in operation without a jerk. It yields, recoils, and so forms the most perfect spring; admirably calculated to carry the head without jar, or injury of any kind.

The most unhappy illustration of all this is the condition of old age. The tables of the skull are then consolidated, and the spine is rigid: if an old man should fall with his head upon the carpet, the blow, which would be of no consequence to the elastic frame of a child, may to him prove fatal; and the rigidity of the spine makes every step which he takes vibrate to the interior of the head, and jar on the brain.

We have hinted at a comparison betwixt the attachment of the spine to the pelvis and the insertion of the mast of a ship into the hull. The mast goes directly through the decks without touching them, and the heel of the mast goes into

the step, which is formed of large solid pieces of oak timber laid across the keelson. The keelson is an inner keel resting upon the floor-timbers of the ship and directly over the proper keel. These are contrivances for enlarging the base on which the mast rests as a column: for as, in proportion to the height and weight of a column, its base must be enlarged, or it would sink into the earth; so, if the mast were to bear upon a point, it would break through the bottom of the ship.

The mast is supported upright by the shrouds and stays. The shrouds secure it against the lateral or rolling motion, and the stays and back-stays against the pitching of the ship. These form what is termed the standing rigging. The mast does not bear upon the deck or on the beams of the ship; indeed, there is a space covered with canvas betwixt the deck and the mast.

We often hear of a new ship going to sea to stretch her rigging; that is, to permit the shrouds and stays to be stretched by the motion of the ship, after which they are again braced tight: for if she were overtaken by a storm before this operation, and when the stays and shrouds were relaxed, the mast would lean against the upper deck, by which it would be sprung or carried away. Indeed, the greater proportion of masts that are lost are lost in this manner. There are no boats which keep the sea in such storms as

those which navigate the gulf of Finland. Their masts are not attached at all to the hull of the ship, but simply rest upon the step.

Although the spine has not a strict resemblance to the mast, the contrivances of the shipbuilder, however different from the provisions of nature, show what object is to be attained; and when we are thus made aware of what is necessary to the security of a column on a movable base, we are prepared to appreciate the superior provisions of nature for giving security to the human spine.

The human spine rests on what is called the *pelvis*, or basin; — a circle of bones, of which the haunches are the extreme lateral parts; and the sacrum (which is as the keystone of the arch) may be felt at the lower part of the back. To this central bone of the arch of the pelvis the spine is connected; and, taking the similitude of the mast, the sacrum is as the *step* on which the base of the pillar, like the heel of the mast, is socketed or mortised. The spine is tied to the lateral parts of the pelvis by powerful ligaments, which may be compared to the shrouds. They secure the lower part of the spine against the shock of lateral motion or rolling; but, instead of the stays to limit the play of the spine forwards and backwards in pitching, or to adjust the rake of the mast, there is a very beautiful contrivance in the lower part of the column.

The spine forms here a semicircle which has this effect: that, whether by the exertion of the lower extremities, the spine is to be carried forward upon the pelvis, or whether the body stops suddenly in running, the jar which would necessarily take place at the lower part of the spine A, if it stood upright like a mast, is distributed over several of the bones of the spine, 1, 2, 3, 4, and, therefore, the chance of injury at any particular part is diminished.

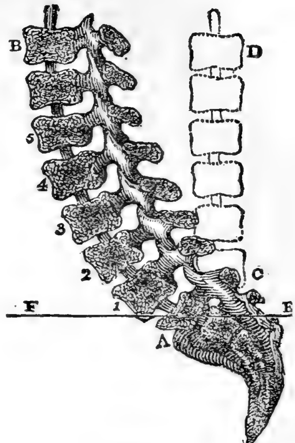


FIG. 6.

For example, the sacrum, or centre bone of the pelvis, being carried forward, as when one is about to run, the force is communicated to the lowest bone of the spine. But, then, the surfaces of these bones stand with a very slight degree of obliquity to the line of motion; the shock communicated from the lower to the second bone of the vertebræ is still in a direction very nearly perpendicular to its surface of contact. The same takes place in the communication of force from the second to the third, and from the third to the fourth; so that before the shock of the horizontal motion acts upon the perpendicular spine, it

is distributed over four bones of that column, instead of the whole force being concentrated upon the joining of any two, as at A.

If the column stood upright, as indicated at C D, it would be jarred at the lowest point of contact with its base. But by forming a semicircle A B, the motion which, in the direction E F, would produce a jar on the very lowest part of the column is distributed over a considerable portion of the column A B; and in point of fact, this part of the spine never gives way. Indeed, we should be inclined to offer this mode to the consideration of nautical men, as fruitful in hints for improving naval architecture.

Every one who has seen a ship pitching in a heavy sea must have asked himself why the masts are not upright, or rather, why the foremast stands upright, whilst the main and mizzen masts stand oblique to the deck, or, as the phrase is, rake aft or towards the stern of the ship.

The main and mizzen masts incline backwards, because the strain is greatest in the forward pitch of the vessel; for the mast having received an impulse forwards, it is suddenly checked as the head of the ship rises; but the mast being set with an inclination backwards, the motion falls more in the perpendicular line from the head to the heel. This advantage is lost in the upright position of the foremast, but it is sacrificed to a

superior advantage gained in working the ship; the sails upon this mast act more powerfully in swaying the vessel round, and the perpendicular position causes the ship to tack or stay better; but the perpendicular position, as we have seen, causes the strain in pitching to come at right angles to the mast, and is, therefore, more apt to spring it.

These considerations give an interest to the fact, that the human spine, from its utmost convexity near its base, inclines backwards.

CHAPTER III

OF THE CHEST

In extending the parallel which we proposed between the structure of the body and the works of human art, it signifies very little to what part we turn; for the happy adaptation of means to the end will everywhere challenge our admiration, in exact proportion to our success in comprehending the provisions which Supreme Wisdom has made. We turn now to a short view of the bones of the chest.

The thorax, or chest, is composed of bones and cartilages, so disposed as to sustain and protect the most vital parts, the heart and lungs, and to turn and twist with perfect facility in every motion of the body; and to be in incessant motion in the act of respiration, without a moment's interval, during a whole life. In anatomical description, the thorax is formed of the vertebral column, or spine, on the back part, the ribs on either side, and the breastbone, or sternum, on the forepart. But the thing most to be admired is the manner in which these bones are united, and especially the manner in which the ribs are joined to the

breastbone by the interposition of cartilages, or gristle, of a substance softer than bone, and more elastic and yielding. By this quality they are fitted for protecting the chest against the effects of violence, and even for sustaining life after the muscular power of respiration has become too feeble to continue without this support.

If the ribs were complete circles, formed of bone, and extending from the spine to the breastbone, life would be endangered by any accidental fracture; and even the rubs and jolts to which the human frame is continually exposed would be too much for their delicate and brittle texture. But these evils are avoided by the interposition of the elastic cartilage. On their forepart the ribs are eked out, and joined to the breastbone by means of cartilages, of a form corresponding to that of the ribs, being, as it were, a completion of the arch of the rib, by a substance more adapted to yield in every shock or motion of the body. The elasticity of this portion subdues those shocks which would occasion the breaking of the ribs. We lean forward, or to one side, and the ribs accommodate themselves, not by a change of form in the bones, but by the bending or elasticity of the cartilages. A severe blow upon the ribs does not break them, because their extremities recoil and yield to the violence. It is only in youth, however, when the human frame is in per-

fection, that this pliancy and elasticity have full effect. When old age approaches, the cartilages of the ribs become bony. They attach themselves firmly to the breastbone, and the extremities of the ribs are fixed, as if the whole arch were formed of bone unyielding and inelastic. Then every violent blow upon the side is attended with fracture of the rib, an accident seldom occurring in childhood or in youth.

But there is a purpose still more important to be accomplished by means of the elastic structure of the ribs, as partly formed of cartilage. This is in the action of breathing, or respiration; especially in the more highly raised respiration which is necessary in great exertions of bodily strength, and in violent exercise. There are two acts of breathing — *expiration*, or the sending forth of the breath; and *inspiration*, or the drawing in of the breath. When the chest is at rest, it is neither in the state of expiration nor in that of inspiration; it is in an intermediate condition between these two acts. And the muscular effort by which either inspiration or expiration is produced is an act in opposition to the elastic property of the ribs. The property of the ribs is to preserve the breast in the intermediate state between expiration and inspiration. The muscles of respiration are excited alternately, to dilate or to contract the cavity of the chest, and, in doing

so, to raise or to depress the ribs. Hence it is, that both in inspiration and in expiration the elasticity of the ribs is called into play; and, were it within our province, it would be easy to show, that the dead power of the cartilages of the ribs preserves life by respiration, after the vital muscular power would, without such assistance, be too weak to continue life.

It will at once be understood, from what has now been explained, how, in age, violent exercise or exertion is under restraint, in so far as it depends on respiration. The elasticity of the cartilages is gone, the circle of the ribs is now unyielding, and will not allow that high breathing, that sudden and great dilating and contracting of the cavity of the chest, which is required for circulating the blood through the lungs, and relieving the heart amidst the more tumultuous flowing of the blood which exercise and exertion produce.

CHAPTER IV

DESIGN SHOWN IN THE STRUCTURE OF THE BONES AND JOINTS OF THE EXTREMITIES

THAT the bones, which form the interior of animal bodies, should have the most perfect shape, combining strength and lightness, ought not to surprise us, when we find this in the lowest vegetable production.

In the sixteenth century, an unfortunate man who taught medicine, philosophy, and theology, was accused of atheistical opinions, and condemned to have his tongue cut out, and to suffer death. When brought from his cell before the Inquisition, he was asked if he believed in God. Picking up a straw which had stuck to his garments, "If," said he, "there was nothing else in nature to teach me the existence of a Deity, even this straw would be sufficient!"

A reed, or a quill, or a bone, may be taken to prove that in Nature's works strength is given with the least possible expense of materials. The long bones of animals are, for the most part, hollow cylinders, filled up with the lightest substance, marrow; and in birds the object is attained

by means (if we may be permitted to say so) still more artificial. Every one must have observed, that the breastbone of a fowl extends along the whole body, and that the body is very large compared with the weight: this is for the purpose of rendering the creature specifically lighter and more buoyant in the air; and that it may have a surface for the attachment of muscles, equal to the exertion of raising it on the wing. This combination of lightness with increase of volume is gained by air-cells extending through the body, and communicating by tubes between the lungs and cavities of the bones. By these means, the bones, although large and strong to withstand the operation of powerful muscles upon them, are much lighter than those of quadrupeds.

The long bones of the human body, being hollow tubes, are called cylindrical, though they are not accurately so, the reason of which we shall presently explain; and we shall, at the same time, show that their irregularities are not accidental, as some have imagined. But let us first demonstrate the advantage which, in the structure of the bones, is derived from the cylindrical form, or a form approaching to that of the cylinder. If a piece of timber supported on two points (*Fig.* 7) bear a weight upon it, it sustains this weight by different qualities in its different parts. For example, divide it into three equal

parts (A, B, C): the upper part A supports the weight by its solidity and resistance to compression; the lowest part B, on the other hand, resists by its toughness, or adhesive quality. Betwixt the portions

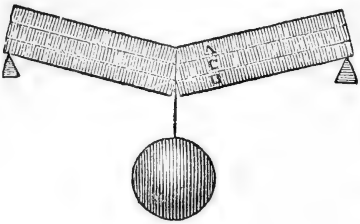


FIG. 7.

acting in so different a manner there is an intermediate neutral, or central part C, that may be taken away without materially weakening the beam, which shows that a hollow cylinder is the form of strength. The writer lately observed a good demonstration of this: — A large tree was blown down, and lay upon the ground; to the windward, the broken part gaped; it had been torn asunder like the snapping of a rope: to the leeward side of the tree, the fibres of the stem were crushed into one another and splintered; whilst the central part remained entire. This, we presume, must be always the case, more or less; and here we take the opportunity of noticing why the arch is the form of strength. If this transverse piece of timber were in the form of an arch, and supported at the extremities, then its whole thickness, its centre, as well as the upper and lower parts, would support weight by resisting compression. But the demonstration may be carried

much farther to show the form of strength in the bone. If the part of the cylinder which bears the pressure be made more dense, the power of resistance will be much increased; whereas, if a ligamentous covering be added on the other side, it will strengthen the part which resists extension: and we observe a provision of this kind in the tough ligaments which run along the vertebræ of the back.

When we see the bone cut across, we are forced to acknowledge that it is formed on the principle of the cylinder; that is, that the material is removed from the centre, and accumulated on the circumference (*Fig.* 8). We find a spine, or ridge running along the bone, which, when divided by the saw in a transverse direction, exhibits an irregularity, as at A.

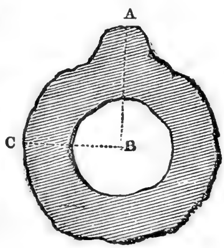


Fig. 8.

The section of this spine shows a surface as dense as ivory, which is, therefore, much more capable of resisting compression than the other part of the cylinder, which is common bone. This declares what the spine is, and the anatomists must be wrong who imagine that the bone is moulded by the action of the muscle, and that the spine is a mere ridge, arising by accident among the muscles. It is, on the contrary, a strength-

ening of the bone in the direction on which the weight bears. If we resume the experiment with the piece of timber, we shall learn why the spine is harder than the rest of the bone. If a portion of the upper part of the timber be cut away, and a harder wood inserted in its place, the beam will acquire a new power of resisting fracture, because, as we have stated, this part of the wood does not yield but by being crushed, and the insertion of the harder portion of wood increases this property of resistance. With this fact before us we may return to the examination of the spine of bone. We see that it is calculated to resist pressure, first, because it is farther removed from the centre of the cylinder; and, secondly, because it is denser, to resist compression, than the other part of the circumference of the bone.[1]

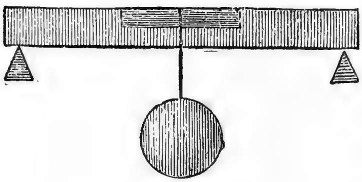


FIG. 9.

This explanation of the use of a spine upon a bone gives a new interest to osteology.[2] The anatomist ought to deduce from the form of the spine the motions of the limb; the forces bearing

[1] As the line A B extends farther from the centre than B C, on the principle of a lever, the resistance to transverse fracture will be greater in the direction A B than B C.

[2] *Osteology*, from the Greek words, signifying discourse on bone, being the demonstration of the forms and connection of the different bones.

upon the bone, and the nature and the common place of fracture: while, to the general inquirer, an agreeable process of reasoning is introduced in that department, which is altogether without interest when the "*irregularities*" of the bone are spoken of, as if they were the accidental consequences of the pressure of the flesh upon it.

Although treating of the purely mechanical principle, it is, perhaps, not far removed from our proper object to remark, that a person of feeble texture and indolent habits has the bone smooth, thin, and light; but that Nature, solicitous for our safety, in a manner which we could not anticipate, combines with the powerful muscular frame a dense and perfect texture of bone, where every spine and tubercle is completely developed. And thus the inert and mechanical provisions of the bone always bear relation to the muscular power of the limb, and exercise is as necessary to the perfect constitution of a bone as it is to the perfection of the muscular power. Jockeys speak correctly enough, when they use the term "*blood and bone*" as distinguishing the breed or genealogy of horses; for blood is an allowable term for the race, and bone is so far significant, that the bone of a running horse is remarkably compact compared with the bone of a draught horse. The reader can easily understand, that the span in the gallop must give a shock in proportion

to its length; and, as in man, so in the horse, the greater the muscular power the denser and stronger is the bone.

The bone not being as a mere pillar, intended to bear a perpendicular weight, we ought not to expect uniformity in its shape. Each bone, according to its place, bears up against the varying forces that are applied to it. Consider two men wrestling together, and then think how various the property of resistances must be: here they are pulling, and the bones are like ropes; or, again, they are writhing and twisting, and the bones bear a force like the axle-tree between two wheels; or they are like a pillar under a great weight; or they are acting as a lever.

To withstand these different shocks, a bone consists of three parts, the *earth* of bone (subphosphate of lime); *fibres* to give it toughness; and *cartilage* to give it elasticity. These ingredients are not uniformly mixed up in all bones; but some bones are hard, from the prevalence of the earth of bone; some more fibrous, to resist a pull upon them; and some more elastic, to resist the shocks in walking, leaping, etc. But to return to the forms:—Whilst the centre of the long bones is, as we have stated, cylindrical, their extremities are expanded, and assume various shapes. The expansion of the head of the bone is to give a greater, and consequently a more

secure surface for the joint, and its form regulates the direction in which the joint is to move. A jockey, putting his hand on the knee of a colt, and finding it broad and flat, augurs the perfection of the full-grown horse. To admit of this enlargement and difference of form, a change in the internal structure of the bone is necessary, and the hollow of the tube is filled up with *cancelli*, or lattice-work. These *cancelli* of the bone are minute and delicate-like wires, which form lattice-work, extending in all directions through the interior of the bone, and which, were it elastic, would be like a sponge. — This more uniform texture of the bone permits the outer shell to be very thin, so that whilst the centre of the long bones are cylinders, their extremities are of a uniform cancellated structure. But it is pertinent to our purpose to notice, that this minute lattice-work, or the cancelli which constitute the interior structure of bone, have still reference to the forces acting on the bone; if any one doubts this, let him make a section of the upper and lower end of the thighbone, and let him inquire what is the meaning of the difference in the *lie* of these minute bony fibres, in the two extremities? He will find that the head of the thighbone stands obliquely off from the shaft, and that the whole weight bears on what is termed the *inner trochanter;* and to that point, as to

a buttress, all these delicate fibres converge, or point from the head and neck of the bone, which may be rudely represented in this way.

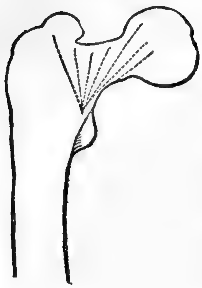


Fig. 10.

We may here notice an opinion that has been entertained, in regard to the size of animals. It is believed that the material of bone is not capable of supporting a creature larger than the elephant, or the *mastodon*, which is the name of an extinct animal of great size, the osseous remains of which are still found. This opinion is countenanced by observing that their bones are very clumsy, that their spines are of great thickness, and that their hollow cylinders are almost filled up with bone.

It may be illustrated in this manner: — A soft stone projecting from a wall may make a stile, strong enough to bear a person's weight; but if it were necessary to double its length, the thickness must be more than doubled, or a freestone substituted; and were it necessary to make this freestone project twice as far from the wall, even if doubled in thickness, it would not be strong enough to bear a proportioned increase of weight: granite must be placed in its stead; and even the granite would not be capable of sustaining four times the weight which the soft stone bore in the

first instance. In the same way the stones which form an arch of a large span must be of the hardest granite, or their own weight would crush them. The same principle is applicable to the bones of animals. The material of bone is too soft to admit an indefinite increase of weight; and it is another illustration of what was before stated, that there is a relation established through all nature, and that the very animals which move upon the surface of the earth are proportioned *to its magnitude*, and the gravitation to its centre. Archdeacon Paley has with great propriety taken the instance of the form of the ends of bones, as proving design in the mechanism of a joint. But there is something so highly interesting in the conformation of the whole skeleton of an animal, and the adaptation of any one part to all the other parts, that we must not let our readers remain ignorant of the facts, or of the important conclusions drawn from them.

What we have to state has been the result of the studies of many naturalists; but although they have labored, as it were, in their own department of comparative anatomy, they have failed to seize upon it with the privilege of genius, and to handle it in the masterly manner of Cuvier.

Suppose a man ignorant of anatomy to pick up a bone in an unexplored country, he learns nothing, except that some animal has lived and

died there; but the anatomist can, by that single bone, estimate, not merely the size of the animal, as well as if he saw the print of its foot, but the form and joints of the skeleton, the structure of its jaws and teeth, the nature of its food, and its internal economy. This, to one ignorant of the subject, must appear wonderful, but it is after this manner that the anatomist proceeds: let us suppose that he has taken up that portion of bone in the limb of the quadruped which corresponds to the human wrist; and that he finds that the form of the bone does not admit of free motion in various directions, like the paw of the carnivorous creature. It is obvious, by the structure of the part, that the limb must have been merely for supporting the animal, and for progression, and not for seizing prey. This leads him to the fact that there were no bones resembling those of the hand and fingers, or those of the claws of the tiger; for the motions which that conformation of bones permits in the paw would be useless without the rotation of the wrist — he concludes that these bones were formed in one mass, like the cannon bone, pastern bone, and coffin bones of the horse's foot.[1]

[1] For these are solid bones, where it is difficult to recognize any resemblance to the carpus, metacarpus, and bones of the fingers; and yet comparative anatomy proves that these movable bones are of the same class with those in the solid hoof of the *belluæ* of Linnæus.

The motion limited to flection and extension of the foot of a hoofed animal implies the absence of a collar bone and a restrained motion in the shoulder joint; and thus the naturalist, from the specimen in his hand, has got a perfect notion of all the bones of the anterior extremity! The motions of the extremities imply a condition of the spine which unites them. Each bone of the spine will have that form which permits the bounding of the stag, or the galloping of the horse, but it will not have that form of joining which admits the turning or writhing of the spine, as in the leopard or the tiger.

And now he comes to the head: the teeth of a carnivorous animal, he says, would be useless to rend prey, unless there were claws to hold it, and a mobility of the extremities like the hand, to grasp it. He considers, therefore, that the teeth must have been for bruising herbs, and the back teeth for grinding. The socketing of these teeth in the jaw gives a peculiar form to these bones, and the muscles which move them are also peculiar; in short, he forms a conception of the shape of the skull. From this point he may set out anew, for by the form of the teeth, he ascertains the nature of the stomach, the length of the intestines, and all the peculiarities which mark a vegetable feeder.

Thus the whole parts of the animal system are

so connected with one another, that from one single bone or fragment of bone, be it of the jaw, or of the spine, or of the extremity, a really accurate conception of the shape, motions, and habits of the animal may be formed.

It will readily be understood, that the same process of reasoning will ascertain, from a small portion of a skeleton, the existence of a carnivorous animal, or of a fowl, or of a bat, or of a lizard, or of a fish; and what a conviction is here brought home to us, of the extent of that plan which adapts the members of every creature to its proper office, and yet exhibits a system extending through the whole range of animated beings, whose motions are conducted by the operation of muscles and bones.

After all, this is but a part of the wonders disclosed through the knowledge of a thing so despised as a fragment of bone. It carries us into another science; since the knowledge of the skeleton not only teaches us the classification of creatures now alive, but affords proofs of the former existence of animated beings which are not now to be found on the surface of the earth. We are thus led to an unexpected conclusion from such premises: not merely the existence of an individual animal, or race of animals; but even the changes which the globe itself has undergone in times before all existing records, and

before the creation of human beings to inhabit the earth, are opened to our contemplation.

OF STANDING

This may appear to some a very simple inquiry, and yet it is very ignorant to suppose that it is so. The subject has been introduced in this fashion: — "Observe these men engaged in raising a statue to its pedestal with the contrivances of pulleys and levers, and how they have placed it on the pedestal and are soldering it to keep it steady, lest the wind should blow it down. This statue has the fair and perfect proportions of the human body; to all outward appearance it ought to stand."

In the following passage, we have the same idea thrown out in a manner which we are apt to call *French*. Were a man cast on a desert shore, and there to find a beautiful statue of marble, he would naturally exclaim, — "Without doubt, there have been inhabitants here: I recognize the hand of a famous sculptor: I admire the delicacy with which he has proportioned all the members of the body to give them beauty, grace, and majesty, to indicate the motion and expression of life." But it may be asked, what would such a man think if his companion were to say, — "Not at all, no sculptor made this statue; it is formed, to be sure, in the best taste, and according to the

rules of art, but it is formed by chance: amongst the many fragments of marble, there has been one thus formed of itself. The rain and the winds have detached it from the mountain, and a storm has placed it upright on the pedestal. The pedestal, too, was prepared of itself in this lonely place. True, it is like the Apollo, or the Venus, or the Hercules. You might believe that the figure lived and thought; that it was prepared to move and speak; but it owes nothing to art; blind chance has placed it there."[1]

The first passage suggests the conviction that the power of standing proceeds not from any symmetry, as in a pillar, or from gravitation alone. It, in fact, proceeds from an internal provision, by which a man is capable of estimating, with great precision, the inclination of his body, and correcting the bias by the adjustment of the muscles. In the second passage, it is meant to be shown, that the outward proportion of the form bears a relation to the internal structure; that grace and expression are not superficial qualities, and that only the Divine Architect could form such a combination of animated machinery.

We shall consider how the human body is prepared by mechanical contrivances to stand upright, and by what fine sense of the gravitation

[1] *Demonstration de l'Existence de Dieu, par Fénelon.*

of the body the muscles are excited to stiffen the otherwise loose joints, and to poise the body on its base.

OF THE FOOT

Let us take the arrangement of the bones of the foot, according to the demonstration of the anatomists.

They are divided into the *tarsus*, which is composed of seven bones, reaching from the heel to the middle of the foot. The *metatarsus*, which consists of five long bones laid parallel to each other, and extending from the *tarsus* to the roots of the toes. The bones of the toes are called *phalanges*, from being in the form of a *phalanx*.

There are in all thirty-six bones in the foot; and the first question that naturally arises is, Why should there be so many bones? The answer is, In order that there may be so many joints; for the structure of a joint not only permits motion, but bestows elasticity.

A joint then consists of the union of two bones, of such a form as to permit the necessary motion: but they are not in contact: each articulating surface is covered with cartilage, to prevent the jar which would result from the contact of the bones. This cartilage is elastic, and the celebrated Dr. Hunter discovered that the elasticity was in consequence of a number of filaments closely compacted, and extending from the surface of the

bone, so that each filament is perpendicular to the pressure made upon it. The surface of the articulating cartilage is perfectly smooth, and is lubricated by a fluid called *synovia*, signifying a mucilage, a viscous or thick liquor. This is vulgarly called *joint oil*, but it has no property of oil, although it is better calculated than any oil to lubricate the interior of the joint.

When inflammation comes upon a joint, this fluid is not supplied, and the joint is stiff, and the surfaces creak upon one another like a hinge without oil. A delicate membrane extends from bone to bone, confining this lubricating fluid, and forming the boundary of what is termed the cavity of the joint, although, in fact, there is no unoccupied space. External to this capsule[1] of the joint, there are strong ligaments going from point to point of the bones, and so ordered as to bind them together without preventing their proper motions. From this description of a single joint, we can easily conceive what a spring or elasticity is given to the foot, where thirty-six bones are jointed together.

An elegant author has this very natural remark on the joints:—"In considering the joints, there is nothing, perhaps, which ought to move our gratitude more than the reflection, *how well they wear*. A limb shall swing upon its hinge, or

[1] From *capsula*, a little case, or box.

play in its socket, many hundred times in an hour, for sixty years together, without diminution of its agility, which is a long time for anything to last, for anything so much worked and exercised as the joints are. This durability I should attribute, in part, to the provision which is made for the preventing of wear and tear: first, by the polish of cartilaginous surfaces; secondly, by the healing lubrication of the mucilage; and, in part, to that astonishing property of animal constitutions, assimilation, by which, in every portion of the body, let it consist of what it will, substance is restored and waste repaired." — PALEY.

If the ingenious author's mind had been professionally called to contemplate this subject, he would have found another explanation. There is no resemblance betwixt the provisions against the wear and tear of machinery and those for the preservation of a living part. As the structure of the parts is originally perfected by the action of the vessels, the function or operation of the part is made the stimulus to those vessels. The cuticle on the hands wears away like a glove; but the pressure stimulates the living surface to force successive layers of skin under that which is wearing, or, as the Anatomists call it, desquamating; by which they mean, that the cuticle does not change at once, but comes off in *squamæ*, or scales. The teeth are subject to pressure in chew-

ing or masticating, and they would, by this action, have been driven deeper in the jaw, and rendered useless, had there not been a provision against this mechanical effect. This provision is a disposition to grow, or rather to shoot out of their sockets; and this disposition to project balances the pressure which they sustain; and when one tooth is lost, its opposite rises, and is in danger of being lost also, for want of that very opposition.

The most obvious proof of contrivance is the junction of the foot to the bones of the leg at the ankle-joint. The two bones of the leg, called the *tibia* and the *fibula*, receive the great articulating bone of the foot (the *astragalus*) betwixt them. And the extremities of these bones of the leg project so as to form the outer and inner ankle. Now, when we step forward, and whilst the foot is raised, it rolls easily upon the ends of these bones, so that the toe may be directed according to the inequalities of the ground we are to tread upon; but when the foot is planted, and the body is carried forward perpendicularly over the foot, the joint of the leg and foot becomes fixed, and we have a steady base to rest upon. We next observe, that, in walking, the heel first touches the ground. If the bones of the leg were perpendicular over the part which first touches the ground, we should come down with a sudden

jolt, instead of which we descend in a semicircle, the centre of which is the point of the heel.

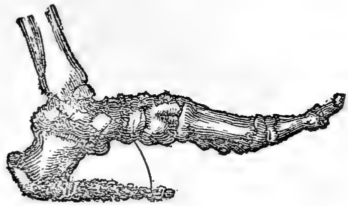


Fig. 11.

And when the toes have come to the ground we are far from losing the advantages of the structure of the foot, since we stand upon an elastic arch, the hinder extremity of which is the heel, and the anterior the balls of the toes. A finely formed foot should be high in the instep. The walk of opera dancers is neither natural nor beautiful; but the surprising exercises which they perform give to the joints of the foot a freedom of motion almost like that of the hand. We have seen the dancers, in their morning exercises, stand for twenty minutes on the extremities of their toes, after which the effort is to bend the inner ankle down to the floor, in preparation for the Bolero step. By such unnatural postures and exercises the foot is made unfit for walking, as may be observed in any of the retired dancers and old *figurantes*. By standing so much upon the toes, the human foot is converted to something more resembling that of a quadruped, where the heel never reaches the ground, and where the paw is nothing more than the phalanges of the toes.

This arch of the foot, from the heel to the toe, has the astragalus (A) resembling the keystone of an arch; but, instead of being fixed, as in masonry, it plays freely betwixt two bones, and from these two bones, B and C, a strong elastic ligament is extended, on which the bone (A) rests, sinking or rising as the weight of the body bears upon it, or is taken off, and this it is enabled to do by the action of the ligament which runs under it.

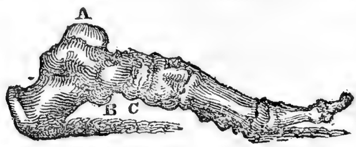


FIG. 12.

This is the same elastic ligament which runs extensively along the back of the horse's hind leg and foot, and gives the fine spring to it, but which is sometimes ruptured by the exertion of the animal in a leap, producing irrecoverable lameness.

Having understood that the arch of the foot is perfect from the heel to the toe, we have next to observe, that there is an arch from side to side; for when a transverse section is made of the bones of the foot, the exposed surface presents a perfect arch of wedges, regularly formed like the stones of an arch in masonry. If we look down upon the bones of the foot, we shall see that they form a complete circle horizontally, leaving a space in their centre. These bones thus form three dif-

ferent arches — forward; across; and horizontally: they are wedged together, and bound by ligaments, and this is what we alluded to when we said that the foundations of the Eddystone were not laid on a better principle; but our admiration is more excited in observing, that the bones of the foot are not only wedged together, like the courses of stone for resistance, but that solidity is combined with elasticity and lightness.

Notwithstanding the mobility of the foot in some positions, yet when the weight of the body bears directly over it, it becomes immovable, and the bones of the leg must be fractured before the foot yields.

We shall proceed to explain how the knee-joint and hip-joint, independently of the exertion of muscles, become firm in the standing position, and when at rest: but, before we enter upon this, let us understand the much-talked-of demonstration of Borelli, who explained the manner in which a bird sits upon a branch when asleep: the weight of the creature and the consequent flexion of the limbs drawing the tendons of the talons, so as to make them grasp the branch without muscular effort.

The muscle A passes over the joint at B, and then proceeds to the back of the leg, and behind the joint at C, and so descends behind the foot at D, and extends to the talons; and the

weight of the bird, bending the joint B and C, produces the effect of muscular effort, and makes the claws cling.

Fig. 13.

But why should the anatomist have recourse to this piece of comparative anatomy, when he has so fine an example in the human body? And one which is much more interesting, as, in fact, it is the foundation of reasoning upon the diseases and accidents of the limb. If this beautiful arrangement in the healthy and perfect structure of a man's limb be not attended to, it would be easy to prove that many important circumstances, in regard to disease and accidents, must remain obscure.

The posture of a soldier under arms, when his heels are close together, and his knees straight, is a condition of painful restraint. Observe, then, the change in the body and limbs, when he is ordered to stand at ease; the firelock falls against his relaxed arms, the right knee is thrown out, and the tension of the ankle-joint of the same

leg is relieved, whilst he loses an inch and a half of his height, and sinks down upon his left hip. This command to "stand at ease" has a higher authority than the general orders. It is a natural relaxation of all the muscles; which are, consequently, relieved from a painful state of exertion: and the weight of the body bears so upon the lower extremity, as to support the joints independently of muscular effort. The advantage of this will be understood, when we consider that all muscular effort is made at the expense of a living power, which, if excessive, will exhaust and weary a man, whilst the position of rest which we are describing is without effort, and therefore gives perfect relief. And it is this which makes boys and girls, who are out of health and languid, lounge too much in the position of relief, from whence comes permanent distortion.

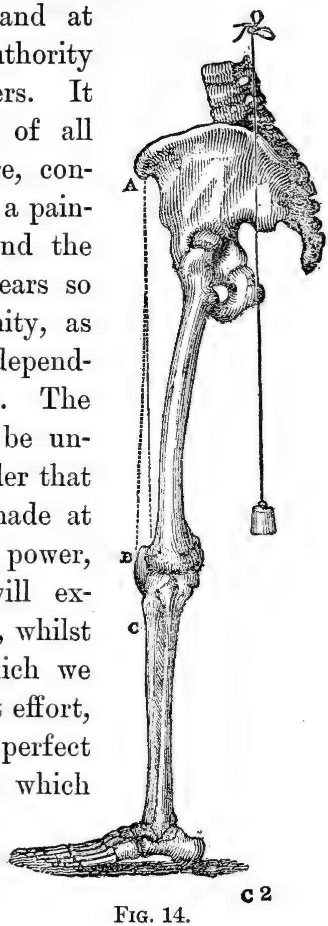


FIG. 14.

Fig. 14 represents the bones of the leg.

The plumb-line shows the direction of the gravitation of the body falling behind the head of the thighbone. Now, if it be understood that the motions of the trunk are performed on the centre of the head of the thighbone; it must follow that the weight of the body in the direction of the plumb-line must raise the corner of the haunchbone, at A. From this corner of the bone, a broad and strong band runs down to the knee-pan, B, in the direction of the dotted line. The powerful muscles which extend the leg are attached to the knee-pan, and through the ligament at C, operate on the bones of the leg, stretching them, and preventing the flexion of the joint; but, in the absence of the activity of these muscles, the band

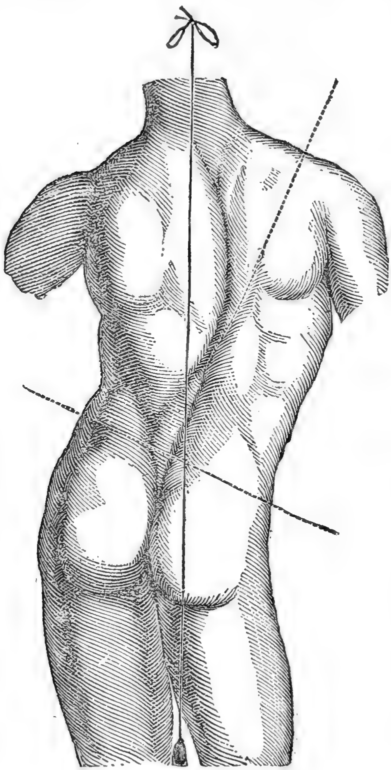


Fig. 15.

reaching from A to B, drawn, as we have said, by the weight of the body, is equivalent to the exertion of the muscles, braces the knee-joint, and extends the leg; and we have before seen that the extension of the leg fixes the ankle-joint. Thus the limb is made a firm pillar under the weight of the body, without muscular effort.

When the human figure is left to its natural attitudes, we see a variety and contrast in the position of the trunk and limbs.

This position of the body resting on the lower extremities throws the trunk into an elegant line, and places the limbs in beautiful contrast, as we see in all the best specimens of sculpture. *See Fig.* 15.

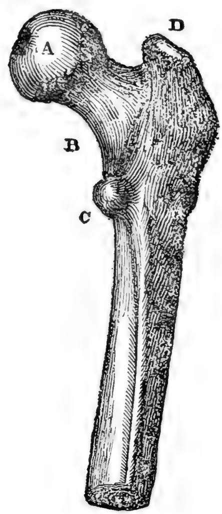


Fig. 16.

Now that we have understood that the lower extremity becomes in some positions a firm pillar, it is the more necessary to observe the particular form of the head of the thighbone (*Fig.* 16).

It is here seen that the head of the bone A stands off from the shaft by the whole length of the neck of the bone B; the effect of this is, that as the powerful muscles are attached to the knobs of bone C D, they turn the

thighbone round in walking with much greater power than if the head of the bone were on a line with the shaft. They, in fact, acquire a lever power, by the distance of D from A; as, during the action of these muscles, the limb is stiff, the rolling of the thigh directs the toe outwards in walking.

When the weight of the body is perpendicularly over the ball of the great toe, the whole body is twisted round on that point as on a pivot. This rolling of the body on the ball of the toe, and consequent turning out of the toes in stepping forward, is necessary to the freedom and elasticity of the motion. The form of all the bones of the leg, and the direction of all the muscles of the thigh and leg, combine to this effect. So far is it from being true, as painters affect to say, that the turning out of the toes is the result of the lessons of the dancing-master.

A certain squareness in the position of the feet is consistent with strength, as we see in the statues of the Hercules, etc.; but the lightness of a Mercury is indicated by the direction of the toes outwards. In women, there would be a defect from the breadth of the pelvis, and a rolling and an awkward gait would be the consequence; but in them the foot is more turned out, and a light, elastic step balances the defect arising from the form of the pelvis. Any one may be con-

vinced of this by observing people who walk awkwardly, especially if they walk unequally. Look at their feet, and you will see that one foot goes straight forward, whilst the other is turned outwards, and that when they come upon the straight foot, they come down awkwardly, and have no spring from it.

There is another curious circumstance in the form of the thighbone, showing how it is calculated for strength as well as freedom of motion. To understand it, we must first look to the *dishing* of a wheel — the dishing is the oblique position of the spokes from the nave to the felly, giving the wheel a slightly conical form. When a cart is in the middle of a road, the load bears equally upon both wheels, and both wheels stand with their spokes oblique to the line of gravitation.

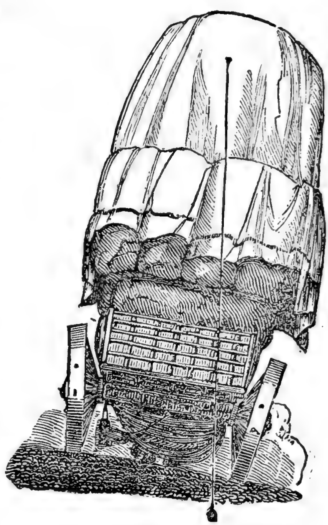


Fig. 17.

If the cart is moving on the side of a barrel-shaped road, or if one wheel falls into a rut, the whole weight comes upon one wheel: but the spokes of that wheel, which were oblique to the

load when it supported only one half of the weight, are now perpendicular under the pressure, and are capable of sustaining the whole. If roads were made perfectly level, and had no holes in them, the wheels of carts might be made without dishing; but if a cart is calculated for a country road, let the wheelwright consider what equivalent he has to give for that very pretty result proceeding from the obliquity of the spokes, or *dishing* of the wheel.

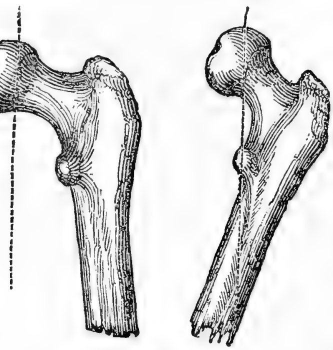


Fig. 18.

When we return to consider the human thighbone, we see that the same principle holds; that is to say, that whilst a man stands on both his legs, the necks of the thighbones are oblique to the line of gravitation of the body; but when one foot is raised, the whole body then being balanced on one foot, a change takes place in the position of the thighbone, and the obliquity of that bone is diminished; or, in other words, now that it has the whole weight to sustain, it is perpendicular under it, and has therefore acquired greater strength. *See Fig.* 18.

CHAPTER V

OF THE TENDONS COMPARED WITH CORDAGE

Where nature has provided a perfect system of columns, and levers, and pulleys, we may anticipate that the cords by which the force of the muscles is concentrated on the movable bones must be constructed with as curious a provision for their offices. In this surmise we shall not be disappointed.

To understand what is necessary to the strength of a rope or cable, we must learn what has been the object of the improvements and patents in this manufacture. The first process in rope-making is hatchelling the hemp; that is, combing out the short fibres, and placing the long ones parallel to one another. The second is spinning the hemp into yarns. And here the principle must be attended to which goes through the whole process in forming a cable; which is, that the fibres of the hemp shall bear an equal strain: and the difficulty may be easily conceived, since the twisting must derange the parallel position of the fibres. Each fibre, as it is twisted, ties the other fibres together, so as to form a continued line,

and it bears at the same time a certain portion of the strain, and so each fibre alternately. The third step of the process is making the yarns. Warping the yarns is stretching them to a certain length; and for the same reason, that so much attention has been paid to the arrangement of the fibres for the yarns, the same care is taken in the management of the yarns for the strands. The fourth step of the process is to form the strands into ropes. The difficulty of the art has been to make them bear alike, especially in great cables, and this has been the object of patent machinery. The *hardening*, by twisting, is also an essential part of the process of rope-making; for without this, it would be little better than extended parallel fibres of hemp. In this twisting, first of the yarns, and then of the strands, those which are on the outer surface must be more stretched than those near the centre; consequently, when there is a strain upon the rope, the outer fibres will break first, and the others in succession. It is to avoid this, that each yarn and each strand, as it is twisted or hardened, shall be itself revolving, so that when drawn into the cable, the whole component parts may, as nearly as possible, resist the strain in an equal degree; but the process is not perfect, and this we must conclude from observing how different the construction of a tendon is from that of a rope. A tendon consists of a

strong cord, apparently fibrous; but which, by the art of the anatomist, may be separated into lesser cords, and these, by maceration, can be shown to consist of cellular membrane, the common tissue that gives firmness to all the textures of the animal body. The peculiarity here results merely from its remarkable condensation. But the cords of which the larger tendon consists do not lie parallel to one another, nor are they simply twisted like the strands of a rope; they are, on the contrary, plaited or interwoven together.

If the strong tendon of the heel, or Achilles tendon, be taken as an example, on first inspection, it appears to consist of parallel fibres, but by maceration, these fibres are found to be a web of twisted cellular texture. If you take your handkerchief, and, slightly twisting it, draw it out like a rope, it will seem to consist of parallel cords; such is, in fact, so far the structure of a tendon. But, as we have stated, there is something more admirable than this, for the tendon consists of subdivisions, which are like the strands of a rope; but instead of being twisted simply as by the process of hardening, they are plaited or interwoven in a way that could not be imitated in cordage by the turning of a wheel. Here, then, is the difference, — by the twisting of a rope, the strands cannot resist the strain equally, whilst we see that this is provided for in the tendon by the

regular interweaving of the yarn, if we may so express it, so that every fibre deviates from the parallel line in the same degree, and, consequently, receives the same strain when the tendon is pulled. If we seek for examples illustrative of this structure of the tendons, we must turn to the subject of ship-rigging, and see there how the seaman contrives, by undoing the strands and yarns of a rope, and twisting them anew, to make his splicing stronger than the original cordage. A sailor opens the ends of two ropes thus:[1] and places the strand of one opposite and between the strand of another, and so interlaces them. And this explains why a hawser-rope, a sort of small cable, is spun of *three* strands; for as they are necessary for many operations in the rigging of a ship, they must be formed in a way that admits of being cut and spliced, for the separation of three strands, at least, is necessary for knotting, spli-

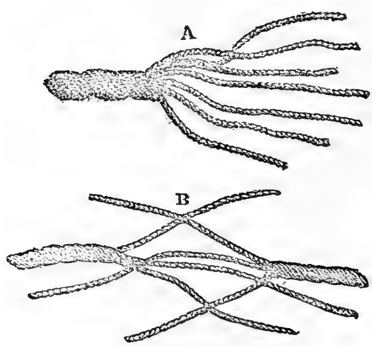


FIG. 19.

[1] A, Strands and yarns opened.
B, Ends opened and laid for splicing, in a manner exactly like the interlacing of the tendon.

cing, whipping, mailing, etc., which are a few of the many curious contrivances for joining the ends of ropes, and for strengthening them by filling up the interstices to preserve them from being cut or frayed. As these methods of splicing and plaiting in the subdivisions of the rope make an intertexture stronger than the original rope, it is an additional demonstration, if any were wanted, to show the perfection of the cordage of an animal machine, since the tendons are so interwoven ; and until the yarns of one strand be separated and interwoven with the yarns of another strand, and this done with regular exchange, the most approved patent ropes must be inferior to the corresponding part of the animal machinery.

A piece of cord of a new patent has been shown to us, which is said to be many times stronger than any other cord of the same diameter. It is so far upon the principle here stated, that the strands are plaited instead of being twisted; but the tendon has still its superiority, for the lesser yarns of each strand in it are interwoven with those of other strands. It, however, gratifies us to see, that the principle we draw from the animal body is here confirmed. It may be asked, do not the tendons of the human body sometimes break? They do; but in circumstances which only add to the interest of the sub-

ject. By the exercise of the tendons (and their exercise is the act of being pulled upon by the muscles, or having a strain made on them), they become firmer and stronger; but in the failure of muscular activity, they become less capable of resisting the tug made upon them, and if, after a long confinement, a man has some powerful excitement to muscular exertion, then the tendon breaks. An old gentleman, whose habits have been long staid and sedentary, and who is very guarded in his walk, is upon an annual festival tempted to join the young people in a dance; then he breaks his tendo Achillis. Or a sick person, long confined to bed, is, on rising, subject to a rupture or hernia, because the tendinous expansions guarding against protrusion of the internal parts have become weak from disuse.

Such circumstances remind us that we are speaking of a living body, and that, in estimating the properties of the machinery, we ought not to forget the influence of life, and that the natural exercise of the parts, whether they be active or passive, is the stimulus to the circulation through them, and to their growth and perfection.

CHAPTER VI

OF THE MUSCLES — OF MUSCULARITY AND ELASTICITY

There are two powers of contraction in the animal frame — elasticity, which is common to living and dead matter, and the muscular power, which is a property of the living fibre.

The muscles are the only organs which properly have the power of contraction, for elasticity is never exerted but in consequence of some other power bending or stretching the elastic body. In the muscles, on the contrary, motion originates; there being no connection, on mechanical principles, betwixt the exciting cause and the power brought into action.

The real power is in the muscles, while the safeguard against the excess of that power is in the elasticity of the parts. This is obvious in the limbs and general texture of the frame; but it is most perfectly exhibited in the organs of circulation. If the action of the heart impelled the blood against parts of solid texture, they would quickly yield. When, by accident, this does take place, even the solid bone is very soon destroyed.

But the coats of the artery which receive the rush of blood from the heart, although thin, are limber and elastic; and by this elasticity or yielding they take off or subdue the shock of the heart's action, while no force is lost; for as the elastic artery has yielded to the sudden impulse of the heart, it contracts by elasticity in the interval of the heart's pulsation; and the blood continues to be propelled onward in the course of the circulation, without interval, though regularly accelerated by the pulse of the heart.

If a steam-engine were used to force water along the water-pipes, without the intervention of some elastic body, the water would not flow continuously, but in jerks, and, therefore, a reservoir is constructed containing air, into which the water is forced, against the elasticity of the air. Thus, each stroke of the piston is not perceptibly communicated to the conduit-pipe, because the intervals are supplied by the push of the compressed air. The office of the reservoir containing air is performed in the animal body by the elasticity of the coats of the arteries, by which means the blood which flows interruptedly into the arteries has a continuous and uninterrupted flow in the veins beyond them.

A muscle is fibrous, that is, it consists of minute threads bundled together, the extremities of which are connected with the tendons which have been

described. Innumerable fibres are thus joined together to form one muscle, and every muscle is a distinct organ. Of these distinct muscles for the motions of the body there are not less than 436 in the human frame, independent of those which perform the internal vital motions. The contractile power, which is in the living muscular fibre, presents appearances which, though familiar, are really the most surprising of all the properties of life. Many attempts have been made to explain this property, sometimes by chemical experiment, sometimes on mechanical principles, but always in a manner repugnant to common sense. We must be satisfied with saying, that it is an endowment, the cause of which it would be as vain to investigate as to resume the search into the cause of gravitation.

The ignorance of the cause of muscular contraction does not prevent us from studying the laws which regulate it, and under this head are included subjects of the highest interest; which, however, we must leave, to pursue the mechanical arrangement of the muscles.

Since we have seen that there are 436 distinct muscles in the body, it is due to our readers to explain how they are associated to effect that combination which is necessary to the motion of the limbs and to our perfect enjoyment. In the first place, the million of fibres which constitute a

single muscle are connected by a tissue of nerves, which produce a union or sympathy amongst them, so that one impulse causes a simultaneous effort of all the fibres attached to the same tendon. When we have understood that the muscles are distinct organs of motion, we perceive that they must be classed and associated in order that many shall combine in one act; and that others, their opponents, shall be put in a state to relax, and offer no opposition to those which are active. These relations can be established only through *nerves*, which are the organs of communication with the brain, or sensorium. The nerves convey the will to the muscles, and at the same time they class and arrange them so as to make them consent to the motions of the body and limbs.

On first looking to the manner in which the muscles are fixed into the bones, and the course of their tendons, we observe everywhere the appearance of a sacrifice of mechanical power, the tendon being inserted into the bone in such a manner as to lose the advantage of the lever. This appears to be an imperfection, until we learn that there is an accumulation of vital power in the muscle in order to attain velocity of movement in the member (*Fig.* 20).

The muscle D, which bends the forearm, is inserted into the radius E, so near the fulcrum, or centre of motion in the elbow-joint, and so

oblique that it must raise the hand and forearm with disadvantage. But, correctly speaking, the power of the muscle is not sacrificed, since it gains more than an equivalent in the rapid and lively motions of the hand and fingers, and since these rapid motions are necessary to us in a thousand familiar actions; and to attain this, the Creator has given sufficient vital power to the muscles to admit of the sacrifice of the mechanical or lever power, and so to provide for every degree and variety of motion which may answer to the capacities of the mind.

If we represent the bones and muscles of the forearm by this diagram, we shall see that power

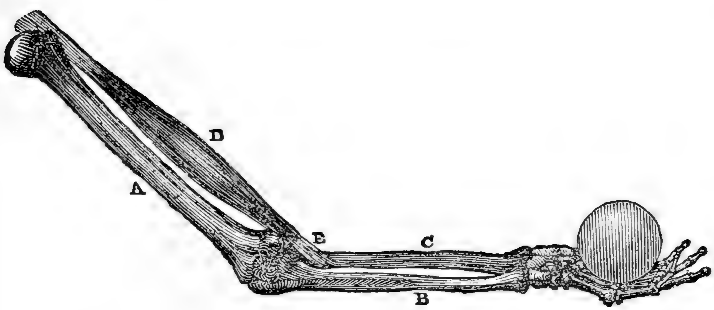


FIG. 20.

is lost by the inclination of the tendon to the lever, into which it is inserted. It represents the lever of the third kind, where the moving power operates on a point nearer the fulcrum than the weight to be moved.

Here A represents the muscle, B the lever, and C the fulcrum. The power of the muscle is not represented by the distance of its insertion *a*, from the fulcrum C. The line which truly represents the lever must pass from the centre of motion, perpendicularly to the line of the tendon, *viz.*, C *b*. Here, again, by the direction of the tendon, as well as by its actual attachment to the bone, power is lost and velocity gained.

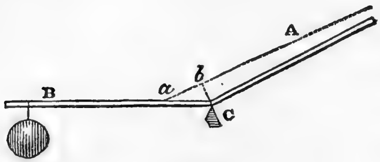


Fig. 21.

We may compare the muscular power to the weight which impels a machine. In studying machinery, it is manifest that weight and velocity are equivalent. The handle of the winch in a crane is a lever, and the space through which it moves, in comparison with the slow motion of the weight, is the measure of its power. If the weight, raised by the crane, be permitted to go down, the wheels revolve, and the handle moves with the velocity of a cannon-ball, and will be as destructive if it hit the workman. The weight here is the power, but it operates with so much disadvantage, that the hand upon the handle of the winch can stop it: but give it way, let the accelerated motion take place, and the hand would be shattered which touched it. Just so the fly-wheel, moving at first

slowly, and an impediment to the working of a machine, at length acquires momentum, so as to concentrate the power of the machine, and enable it to cut bars of iron with a stroke.

The principle holds in the animal machinery. The elbow is bent with a certain loss of mechanical power; but by that very means, when the loss is supplied by the living muscular power, the hand descends through a greater space, moves quicker, with a velocity which enables us to strike or to cut. Without this acquired velocity, we could not drive a nail: the mere muscular power would be insufficient for many actions quite necessary to our existence.

Let us take some examples to show what objects are attained through the oblique direction of the fibres of the muscle, and we shall see that here, as well as by the mode of attachment of the entire muscle, velocity is attained by the sacrifice of power. Suppose that these two pieces of wood (*Fig.* 22) be drawn together by means of a cord, but that the hand which pulls, although possessing abundant strength, wants room to recede more than what is equal to one third of the space betwixt the pieces of wood; it is quite clear, that if the hand were to draw direct on the cord A B, the point A would be brought towards B, through one third only of the intervening space, and the end would not be accomplished. But if

the cord were put over the ends of the upper piece, C D E, and, consequently, directed obliquely to their attachment at A, on drawing the hand back a very little, but with more force, the lower piece of wood would be suddenly drawn up to the higher piece, and the object attained. Or we may put it in this form: — If a muscle be in the direction of its tendon, the motion of the extremity of the tendon will be the same with that of the muscle itself: but if the attachment of the muscle to the tendon be oblique, it will draw the tendon through a greater space; and if the direction of the muscle deviate so far from the line of the tendon as to be perpendicular to it, it will then be in a condition to draw the tendon through the greatest space with the least contraction of its own length. Thus, if A B be a tendon, and C D a muscle, by the contraction of C to D the extremities of the tendon A B will be brought together, through a space double the contraction of the muscle. It is the adjustment, on the same principle, which gives the arrow so quick an impulse

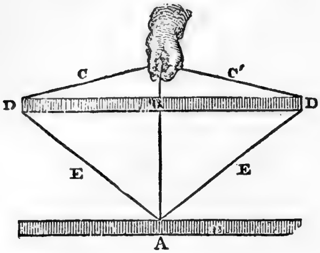


FIG. 22.

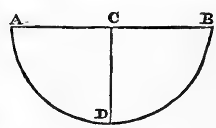


FIG. 23.

from the spring of the bow, the extremities of the bow drawing obliquely on the string.

To free breathing, it is necessary that the ribs shall approach each other, and this is performed by certain *intercostal* muscles (or muscles playing between the ribs), and now we can answer the question, why are the fibres of these muscles oblique?

Let us suppose this figure to represent two ribs with thin intervening muscles. If the fibres of the muscle were in the direction A, across, and

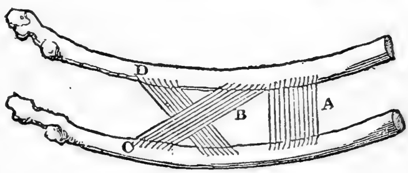


Fig. 24.

perpendicular to the ribs; and if they were to contract one third of their length, they would not close the intervening space — they would not accomplish the purpose. But being oblique, as at B, although they contract no more than one third of their length, they will bring the ribs C, D together. By this obliquity of the intercostal muscles, they are enabled to expand the chest in inspiration, in a manner which could not be otherwise accomplished.

In the greater number of muscles the same principle directs the arrangement of the fibres; they exchange power for velocity of movement, by their obliquity. They do not go direct from

origin to insertion, but obliquely, thus, from tendon to tendon: —

Fig. 25.

Supposing the point A to be the fixed point, these fibres draw the point B with less force, but through a larger space, or more quickly than if they took their course in direct lines; and by this arrangement of the fibres the freedom and extent of motion in our limbs are secured.

But the muscles must be strengthened by additional courses of fibres, because they are oblique; since by their obliquity they lose something of their force of action: and therefore it is, we must presume, that we find them in a double row, making what is termed the *penniform* muscle, thus, —

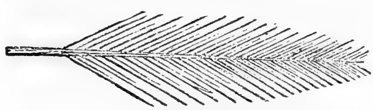


Fig. 26.

and sometimes the texture of the muscle is still further compounded by the intermixture of tendons, which permit additional series of fibres; and all this for the obvious purpose of accumulating power, which may be exchanged for velocity of movement.

We may perceive the same effect to result from the course of the tendons, and their confinement

in sheaths, strengthened by cross-straps of ligament. If the tendon, A (*Fig.* 27), took the shortest course to its termination at B, it would draw up the toe with greater force; but then the toe

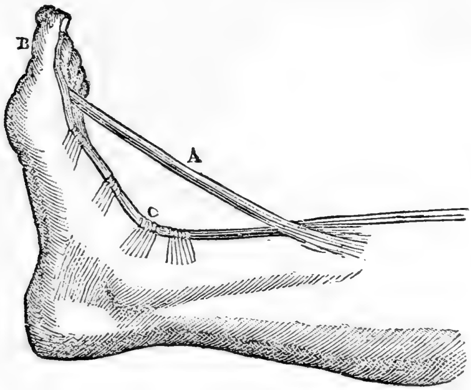


FIG. 27.

would lose its velocity of movement. By taking the direction C, close to the joints, the velocity of motion is secured, and by this arrangement the toes possess their spring, and the fingers their lively movements. We may take this opportunity of noticing how the mechanical opposition is diminished as the living muscular power is exhausted. For example, in lifting a weight, the length of the lever of resistance will be from the centre of the elbow-joint, A (*Fig.* 28), to the centre of the weight, B. As the muscles of the arm contract, they lose something of their power; but in a greater proportion is the mechanical

resistance diminished, for when the weight is raised to C A D, it becomes the measure of the lever of resistance.

A more admirable thing is witnessed by the anatomist, — we mean the manner in which the lever, rising or falling, is carried beyond the sphere of action of one class of muscles, and enters the sphere of activity of others. And this adaptation of the organs of motion is finely adjusted to the mechanical resistance which may arise from the form or motion of the bones. In short, whether we contemplate the million of fibres which constitute one muscle, or the many muscles which combine to the movement of the limb, nothing is more surprising and admirable than the adjustment of their power so as to balance mechanical resistance, arising from the change of position of the levers.

In the animal body, there is a perfect relation preserved betwixt the parts of the same organ. The muscular fibres forming what is termed the belly of the muscle, and the tendon through which the muscle pulls, are two parts of one organ; and the condition of the tendon indicates the state of the muscle. Thus jockeys discover the qualities of a horse by its sinews or tendons. The most approved form in the leg of the hunter, or hackney, is that in which three convexities can be distinguished, — the bone; the prominence of

the elastic ligament behind the bone; and behind that the flexor tendons, large, round, and strong. Strong tendons are provided for strong muscles, and the size of these indicate the muscular strength. Such muscles, being powerful flexors, cause high and round action, and such horses are

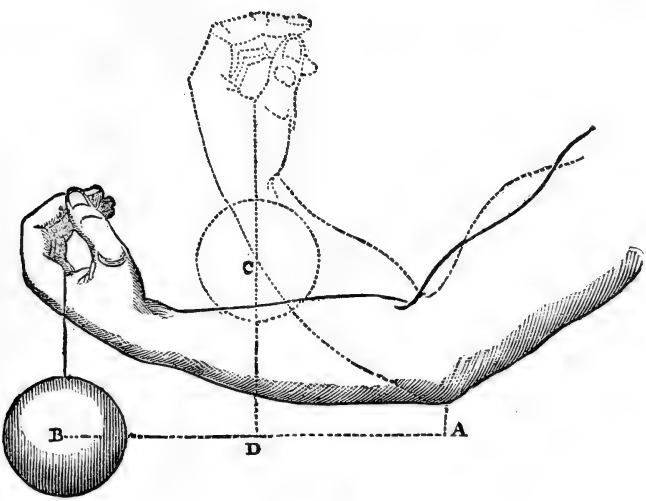


FIG. 28.

safe to ride; their feet are generally preserved good, owing to the pressure they sustain from their high action. But this excellence in a horse will not make him a favorite at Newmarket. The circular motion cannot be the swiftest; a blood-horse carries his foot near the ground. The speed of a horse depends on the strength of his loins and hind quarter; and what is required

in the forelegs is strength of the extensor tendons, so that the feet may be well thrown out before, for if these tendons be not strong, the joints will be unable to sustain the weight of his body, when powerfully thrown forward, by the exertion of his hind-quarters, and he will be apt to come with his nose to the ground.

The whole apparatus of bones and joints being thus originally constituted by nature in accurate relation to the muscular powers, we have next to observe, that this apparatus is preserved perfect by exercise. The tendons, the sheaths in which they run, the cross ligaments by which they are restrained, and the *bursæ muscosæ*[1] which are interposed to diminish friction, can be seen in perfection only when the animal machinery has been kept in full activity. In inflammation, and pain, and necessary restraint, they become weak; and even confinement, and want of exercise, without disease, will produce imperfections. Exercise unfolds the muscular system, producing a full bold outline of the limbs, at the same time that the joints are knit, small, and clean. In the loins, thighs, and legs of a dancer we see the muscular system fully developed; and when we

[1] These *bursæ mucosæ* (mucous purses) are sacs containing a lubricating fluid. They are interposed wherever there is much pressure or friction, and answer all the purposes of friction-wheels in machinery.

turn our attention to his puny and disproportioned arms, we acknowledge the cause — that, in the one instance, exercise has produced perfection, and that, in the other, the want of it has occasioned deformity. Look to the legs of a poor Irishman travelling to the harvest with bare feet: the thickness and roundness of the calf show that the foot and toes are free to permit the exercise of the muscles of the leg. Look, again, to the leg of our English peasant, whose foot and ankle are tightly laced in a shoe with a wooden sole, and you will perceive, from the manner in which he lifts his legs, that the play of the ankle, foot, and toes are lost, as much as if he went on stilts, and, therefore, are his legs small and shapeless.

And this brings us naturally to a subject of some interest at present: we mean the new fashion of exercising our youth in a manner which is to supersede dancing, fencing, boxing, rowing, and cricket, and the natural impulse of youth to activity.

By this fashion of training to what are termed *gymnastics*, children at school are to be urged to feats of strength and activity, not restrained by parental authority, nor left to their own sense of pleasurable exertion. They are made to climb, to throw their limbs over a bar, to press their foot close to their hip, their knees close to their stomach; to hang by the arms and raise the body, —

to hang by the feet and knees, — to struggle against each other, by placing the soles of their feet in opposition, and to pull with their hands. No doubt, if such exercises be persevered in, the muscular powers will be strongly developed. But the first question to be considered is the safety of this practice. We have seen a professor of gymnastics, by such training, acquire great strength and prominence of muscles; but by this unnatural increase of muscular power, through the exercises he recommended, he became ruptured on both sides. The same accident has happened to boys too suddenly put on these efforts.

It is proper to observe, that when the muscular power is thus, we may say, preternaturally increased, whether in the instance of a race-horse, an opera dancer, or a pupil of the Calisthenic school, it is not merely necessary to put them on their exercises gradually in each successive lesson, but each day's exertion must be preceded by a wearisome preparation. In the great schools, like that at Stockholm, the master makes the boys walk in a circle; then run, at first gently; and so he gradually brings them into heat, and the textures of their frame are composed to that state of elasticity and equal resistance, as well as to vital energy, which is necessary for the safe display of the greater feats of strength and activity. This caution in the public exercises is the very

demonstration of the dangers of the system. The boys will not be always under this severe control, and yet it is important to their safety.

We may learn how necessary it is to bring the animal system gradually into action from the effects of very moderate exercise on a horse just out of the dealer's hands. The purchaser thinks he may safely drive him ten miles, not aware that the horse has not moved a mile in a week, and the consequence is, inflammation and congestion in his lungs. The regulation in the army has been made on a knowledge of these facts. When young horses are brought from the dealer they are ordered to be walked an hour a day the first week, two hours a day the second week, three hours a day in the third week. They are to be fatigued by walking, but they must not be sweated in their exercise. Horses for the turf, under three years old, in training for the Derby, are brought very slowly to their exercise, beginning with the lounge; then a very light weight is put upon them, and that gradually increased. Indeed, nothing can better show the effects of exercise in perfecting the muscular action than the consequence of the loss of one day's training. It will bring the favorite to the bottom of the list, and that without any suspicion of lameness, but from a knowledge of the fact, that even such a

slight irregularity in his training will have a sensible effect on his speed. Shall the possibility of pecuniary loss excite the jockey to more care for his horse than we, in our rational and humane attention to the education of our youth, pay to their health and safety?

In reflecting on these many proofs of design in the animal body, it must excite our surprise that anatomy is so little cultivated by men of science. We crowd to see a piece of machinery or a new engine, but neglect to raise the covering which would display in the body the most striking proofs of design, surpassing all art in simplicity and effectiveness, and without anything useless or superfluous.

A more important deduction from the view of the animal structure is, that our conceptions of the perfection and beauty in the design of nature are exactly in proportion to the extent of our capacity. We are familiar with the mechanical powers, and we recognize the principles in the structure of the animal machine; and in proportion as we understand the principles of hydrostatics and hydraulics, are able to discern the most beautiful adaptation of them in the vessels of an animal body. But when, to our further progress in anatomy, it is necessary that we should study a matter so difficult as the theory of life,

imperfect principles or wrong conceptions distort and obscure the appearances: false and presumptuous theories are formed, or we are thrown back in disappointment into scepticism, as if chance only could produce that of which we do not comprehend the perfect arrangement. But studies better directed, and prosecuted in a better spirit, prove that the human body, though deprived of what gave it sense and motion, is still a plan drawn in perfect wisdom.

A man possessed of that humility which is akin to true knowledge may be depressed by too extensive a survey of the frame of nature. The stupendous changes which the geologist surveys — the incomprehensible magnitude of the heavenly bodies moving in infinite space, bring down his thoughts to a painful sense of his own littleness: — "To him the earth with men upon it, will not seem much other than an ant-hill, where some ants carry corn, and some carry their young, and some go empty, and all to and fro a little heap of dust." [1]

He is afraid to think himself an object of Divine care; but when he regards the structure of his own body, he learns to consider space and magnitude as nothing to a Creator. He finds that the living being, which he was about to contemn, in comparison with the great system of the

[1] Bacon.

universe, exists by the continuance of a power, no less admirable than that which rules the heavenly bodies; he sees that there is a revolution, a circle of motions no less wonderful in his own frame, in the microcosm of man's body, than in the planetary system; that there is not a globule of blood which circulates, but possesses attraction as incomprehensible and wonderful as that which retains the planets in their orbits.

The economy of the animal body, as the economy of the universe, is sufficiently known to us to compel us to acknowledge an Almighty Power in the creation. What would be the consequence of a further insight — whether it would conduce to our peace or happiness — whether it would assist us in our duties, or divert us from the performance of them, is very uncertain.

CHAPTER VII

BOOKS

RAY, "On the Wisdom of God manifested in the Works of the Creation," has several chapters on the animal economy.

Archdeacon Paley has composed a work of high interest, by taking the common anatomical demonstrations, and presenting them in an elegant and popular form. His work is entitled, Natural Theology; or, Evidences of the Existence and Attributes of the Deity, collected from the Appearances of Nature.

The celebrated Fénelon has, with the same pious object, composed a small duodecimo, in which he draws his arguments from the structure of animal bodies.

Wollaston, in the "Religion of Nature Delineated," has the same train of reflection to prove that there can be no such thing as chance operating in and about what we see or feel; and he says, with great propriety, "How may a man qualify himself so as to be able to judge of the religions professed in the world; to settle his own opinions in disputable matters; and then to enjoy tranquillity of mind, neither disturbing others, nor being disturbed at what passes among them?"

Derham, in sixteen sermons, preached in 1711, at the lecture founded by Mr. Boyle, treats at length of the structure of our organs. These are also published, separately, under the title of Physico-Theology; and they naturally suggest to learned divines the expediency of sometimes expounding to their hearers the evidences of design apparent in the universe, as a sure means of enlightening their understandings, elevating their views, and awakening their piety.[1]

This cultivation of the mind, by exercising it upon the study of proper objects, is a man's first duty to himself. Without it, he can have no steady opinion on points of the nearest concern. He is wrought upon by circumstances which ought not to sway the mind of a sensible man; at one time depressed to the depths of despondency, and, at another, exalted into unreasonable enthusiasm. Without such cultivation, were a man to live a hundred years, he is at last like one cut off in infancy.

[1] Henry Lord Brougham, man of letters, man of science, advocate, orator, statesman, and Lord Chancellor of England, wrote as follows to Sir Charles Bell, after the publication of this treatise: —

"I cannot refrain from telling you the prodigious success your admirable treatise [Animal Mechanics] has among us on this circuit — judges, lawyers, wranglers, metaphysicians, and theologians, men who are devoid of science, saint, savage, and sage, all unite in its praise and in gratitude to you. But should not the subject have a second handling? H. BROUGHAM, *August*, 1827." — *Letters of Sir C. Bell*, 1870, p. 295.

Jeffries Wyman

ANIMAL MECHANICS

ON THE CANCELLATED STRUCTURE OF SOME OF THE BONES OF THE HUMAN BODY

OR

OF THOSE BONES WHICH HAVE A DEFINITE RELATION TO THE ERECT POSITION WHICH IS NATURALLY ASSUMED BY MAN ALONE

BY

JEFFRIES WYMAN, A. M., M. D. H. C.

COMMUNICATED TO THE BOSTON SOCIETY OF NATURAL HISTORY

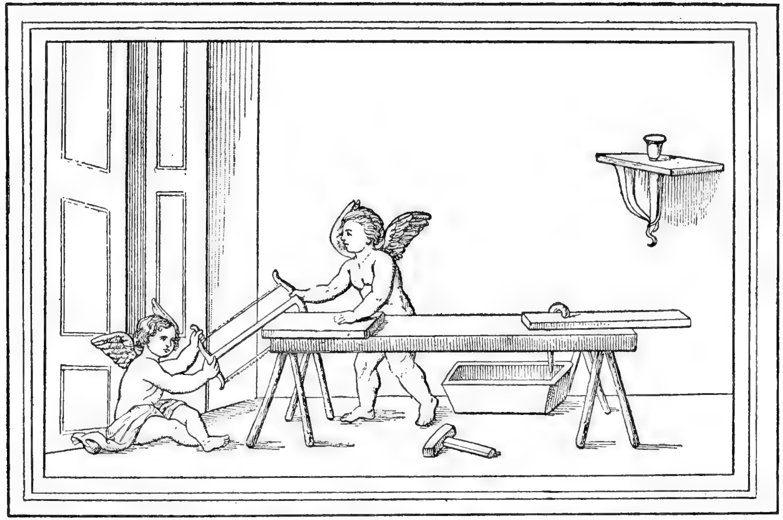
November 7, 1849

JEFFRIES WYMAN

DIED 4th SEPT., 1874

The wisest man could ask no more of Fate
Than to be simple, modest, manly, true,
Safe from the Many, honored by the Few ;
Nothing to court in World, or Church, or State,
But inwardly in secret to be great ;
To feel mysterious Nature ever new,
To touch, if not to grasp, her endless clew,
And learn by each discovery how to wait ;
To widen knowledge and escape the praise ;
Wisely to teach, because more wise to learn ;
To toil for Science, not to draw men's gaze,
But for her lore of self-denial stern ;
That such a man could spring from our decays
Fans the soul's nobler faith until it burn.

JAMES RUSSELL LOWELL.



A ROMAN CARPENTER'S SHOP AT THE CHRISTIAN ERA.

Two little [Genii] carpenters are occupied in sawing a piece of board on a bench with legs. We see the clamp for holding the wood for the workman. On the floor are a hammer and a small box, doubtless for other tools. On a kind of bracket is a cup, probably for oil or glue.—*Herculanum et Pompéi*, Tome iii. Planche 146.

Destroyed by Vesuvius, A. D. 63–79.

ON THE CANCELLATED STRUCTURE OF SOME OF THE BONES OF THE HUMAN BODY

With the exception of the great work of Bourgery and Jacob, Traité Complète de l'Anatomie de l'Homme, and the excellent and instructive Outlines of Human Osteology, by F. O. Ward, nearly all systematic treatises are deficient in descriptions of the mechanical arrangement of the cancellated structure of bones. The student will look in vain through the works of Cruveilhier, Meckel, Bichat, Von Behr, Weber, Soemmering, and Wilson, for any allusion to the manner in which the cancelli are arranged, with reference to the weight which they sustain, and the distribution of that weight to the parts on which they rest. The whole subject is passed by without any other notice than that which would be naturally suggested in describing the "spongy," "reticulated," or "cancellated structure," in contrast with the more dense "compact substance," forming the external walls and crust of the different bones. This is the more remarkable, when it is remembered that the bones have been so perseveringly studied, not only as regards their

external characters, but as to their microscopic structure and chemical composition.

Sir Charles Bell, in his Treatise on Animal Mechanics,[1] alludes to the direction of the cancelli in the neck of the thighbone, but his description will be found, on comparison, to be inaccurate. Mr. Quain, in the last edition of his Anatomy,[2] in referring to the cancellated structure of bones, states correctly the general principle according to which these fibres are arranged. "It may be usually observed," he says, "that the strongest laminæ run through the structure in those directions in which the bone has naturally to sustain the greatest pressure." (Vol. I. p. 75.) But he does not adduce a single instance in illustration of his general proposition.

Bourgery and Jacob, to whom the merit belongs of first calling attention to the subject, have recognized its interest, and have shown that there exists in several of the bones a definite relation between the direction of the cancelli and the weight that the bones, of which they form a part, are destined to sustain. Their description of the neck of the thighbone, it is believed, will be found

[1] *Animal Mechanics, or Proofs of Design in the Animal Frame.* Published by the Society for the Diffusion of Useful Knowledge.

[2] *Human Anatomy,* by Jones Quain, M. D. Edited by Richard Quain, F. R. S., and William Sharpey, M. D., F. R. S. First American Edition. Edited by Joseph Leidy, M. D. Philadelphia: 1849.

on comparison to be incorrect. In the lower extremity of the femur, and in both extremities of the tibia, in the astragalus and os calcis, the cancelli are accurately described and figured. Mr. F. O. Ward, in his Outlines,[1] as regards the structure of the bones of the tarsus, simply follows the descriptions of Bourgery and Jacob. He has attempted a description of the mechanical structure of the neck of the thighbone, but as will be shown further on, there is sufficient reason for regarding his description, as well as that of the last mentioned authors, incorrect in its details. These constitute the only references which I have been able to find, bearing upon the subject of this communication.

Before proceeding to the detailed description of individual parts, it may be proper to state, in general terms, the inferences which are deducible from the structures of the various bones, and, more especially, from those which assist in maintaining the body in its erect position; there are two: —

1. The cancelli of such bones as assist in supporting the weight of the body are arranged either in the direction of that weight, or in such a manner as to support and brace those cancelli which are in that direction. In a mechanical

[1] *Outlines of Human Osteology,* by F. O. Ward. London: 1838.

point of view they may be regarded in nearly all these bones as a series of "studs" and "braces."

2. The direction of these fibres in some of the bones of the human skeleton is characteristic, and, it is believed, has a definite relation to the erect position which is naturally assumed by man alone.

These structures are the most conspicuous in the lumbar portion of the vertebral column, in the thighbone, both in its neck and lower extremity, in the tibia, in the astragalus, and the os calcis. It should be remarked, however, in advance, that they are not equally distinct in the bones of all individuals, nor at all periods of life. The cancelli of the bones of young subjects generally have between them rounded areolæ, and do not appear to assume one direction more than another. In very old subjects they seem to be less clearly defined than in adult and middle-aged skeletons. In these last, while considerable variety exists, I have rarely failed to recognize the general plan of the arrangement of the cancelli. In bones filled with fat the structure is obscured, but it is readily exposed by washing them in a solution of potash or other alkali.

I. VERTEBRÆ

The functions of the vertebræ are threefold: — they serve as columns for the support of

weight; they form, by their union, a canal for the lodgment and protection of the spinal marrow; and constitute a series of levers for the application of muscular force. The first of these functions is performed by the "body," whose special use in a given region is to support the weight of the head, arms, and of all that portion of the trunk which is above it; which weight acquires its maximum in the lumbar region, where the vertebræ acquire their greatest size. The pressure on all the vertebræ is vertical.

If a section be made through a lumbar vertebra, the areolæ between the cancelli will be found to have generally a quadrangular form, and the direction of the cancelli either vertical or transverse (*Fig.* 29 [1]). The vertical ones extending from the upper to the lower face of the vertebra receive the weight which they sustain on their ends; and this they will sustain in virtue of their rigidity. If they have a tendency to yield, it is either by being crushed, or by bending in a lateral direction. This last is prevented by the transverse cancelli which are placed at right angles to the vertical ones, and serve the purpose

[1] This and the following diagrams are intended merely as *plans* of the cancelli, the different lines representing their general directions. For accurate figures of the bones described, except the neck of the thigh, the vertebræ, and astragalus, see the plates of Bourgery and Jacob.

of "braces." The cancelli of the lumbar vertebræ are, therefore, arranged in conformity with the demand for resistance. The arrangement in question is rarely obvious above the last dorsal vertebra; it is, however, present in precisely that

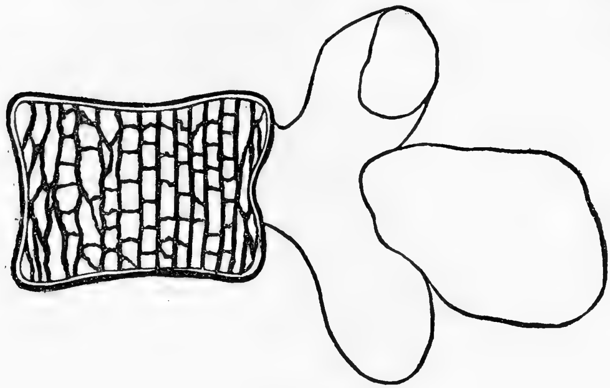


FIG. 29.

part of the column where the pressure, and, consequently, the demand for resistance is greatest.

II. NECK OF THE THIGHBONE

The whole weight of the head, trunk, arms, and pelvis rests on the heads of the two thighbones, or more or less on one of them, according to the attitude of the body when in a state of rest. When the body is in motion they will sustain, in addition to this, the momentum of the trunk as it descends upon them in walking, running, jumping, etc. The heads of the bones are

themselves immediately supported by the neck, the axis of which forms an angle of about 120° with that of the shaft of the bone, if the lower angle be measured, or of 60° if the upper.[1] The weight of the body will, therefore, have an angular bearing upon the axis of the neck, and its tendency will be to bend or break the neck in a downward direction. The means which nature has adopted to counteract this tendency consist :—

1. In making the vertical diameter of the neck

[1] This measurement was made from the specimen which has served for the present description. Great confusion exists in systematic treatises, with regard to the size of the angle which the neck makes with the shaft of the femur. Some writers describe it only in general terms, as Meckel, who refers to it as "un angle presque droit;" Soemering, "un angle aigu;" Cruveilhier and Quain, as "an obtuse angle," etc. Where more precise statements are made, great difference will be found, not only as regards the number of degrees which the angle is estimated to make, but, also, with regard to the angle which is measured; some measuring the angle which the axis of the neck makes with that of the shaft below their union, and others with the continuation of that axis above it. In order, therefore, to compare the different statements, it will be necessary to give, in each case, the complementary angles, and then we can designate the corresponding angles. The angle which the neck makes with the shaft, is, according to

Ward,	125°	comp. angle		55°.
B. Cooper,	45°	"	"	135°.
Morton,	35°–40°	"	"	145°–140°.

Comparing the corresponding angles, we have 125°, 135°, 140°, and 145°, giving a variation of 20°.

the largest, a section at right angles to its axis being oval, and the long diameter perpendicular.

2. In increasing the thickness of the wall of bone on the under side of the neck and adjoining portion of the shaft, on to which a large portion of the weight of the body is directly transmitted.

3. In having the cancelli of each femur so arranged as to form a segment of a framed arch or truss, which coöperates with the external shell in sustaining the weight of the body; the necks of the two femora forming together opposite segments of an arch.

The first and second of these conditions has been frequently adverted to by anatomical writers, but the third has almost invariably escaped observation.

Sir Charles Bell, whose views of the animal mechanism are generally so beautiful and true, has not manifested his usual accuracy in his description of the structure of the neck of the thigh, as given in his tract on Animal Mechanics. One who examines this bone, he says, "will find that the head of the thigh stands obliquely off from the shaft, and that the whole weight bears upon what is termed the *inner trochanter;* and to that point, as to a buttress, all those delicate fibres converge, or point from the neck and head of the bone."[1] A careful examination of a section of

[1] Op. cit., p. 14.

the part in question will show that this description of the cancelli is imperfect as well as incorrect; that the cancelli do not centre on the lesser trochanter, as this process is situated not on the under side of the neck, but on the posterior and inner face of the upper portion of the shaft, and does not, therefore, come within their range. The cancelli converge and bear upon the under thickened and arched shell of bone, but their common centre is at least an inch exterior to and below it.

Bourgery and Jacob, in speaking of the internal structure of the head and neck, describe the first as provided with cancelli forming circular areolæ; the second as made up of two portions — an inferior one consisting of "small parallel columns, which evidently transmit the weight of the superior segment of the head on to the inferior border of the neck. Those parts which are out of the line of pressure (*hors de la ligne de pression*), having nothing to support, will be formed of a more delicate tissue." They also recognize a mass of fibres which enclose the vascular canals, and which "seems to have for its object the union of the head and trochanter with each other and with the shaft of the bone." "It communicates with the head and neck by a fasciculus of radiating fibres, and with the trochanter by a strong lamina, which bifurcates, intercepting two reticular spaces, and externally joins the com-

pact substance. Inferiorly this lamina is again made to bear on the compact substance by a bundle of vertical columns; the central mass descends vertically for the space of an inch and a half in the direction of the axis of the bone, and then expands into a cone which joins the circumference. This cone divides into two masses; an external stronger one, descending obliquely to the right and left, joins the compact substance of the opposite planes of the bone; the internal line follows the course indicated by the base of the neck, and limits the triangular space comprised between it and the great fasciculus of support." [1]

This description is too much confused to be understood without the aid of their figure; and this, it is believed, will be found on comparison with a section of the bone itself to be an inaccurate representation of its structure. The description is correct, as far as it relates to the fibres which transmit the weight from the head to the under side of the neck, though they are not parallel; the "central mass" I have not been able to make out, and as for that portion which is "out of the line of pressure," it has not a structure different from the adjoining parts, and, like them, it performs an important office in sustaining the weight of the body.

Mr. Ward, in his description of the neck, ap-

[1] Bourgery and Jacob, op. cit., Tome I. p. 118.

proaches nearer the truth, though he seems to have misconceived the plan of its structure. He recognizes three series of fibres, one of which extends from the head to the under surface of the neck (*Fig.* 31, *a*); another forming a series of pointed arches which abut on the outer and inner walls of the base of the neck (*b b*); and a third extending from the summit of this arch to the first series (*c*); the whole of which he compares to a bracket (*d*); series (*a*) resisting by its rigidity, (*c*) by its tenacity, and (*b*) forming the "archwork," which gives the last its points of resistance. The cancelli of the triangular interval between these three, he says, present no determinate arrangement. In the sequel it will appear that neither the interval which he describes nor the archwork exists.

According to the view which I wish to advance, and which seems to approach much nearer the truth than either of those above referred to, two series of cancelli exist; one of these (*Fig.* 30, *a a*) rests or abuts on the convex surface of the thick shell which forms the under wall of the neck, and from this they diverge towards the upper portion of the head, neck, trochanter major, and that portion of the shaft just below this last; those which extend into the head are much the longest. The fibres of the second series (*b b*) are arranged in parallel curves, the extremes of which are at-

tached on the one hand to the wall of bone at the base of the great trochanter, and on the other

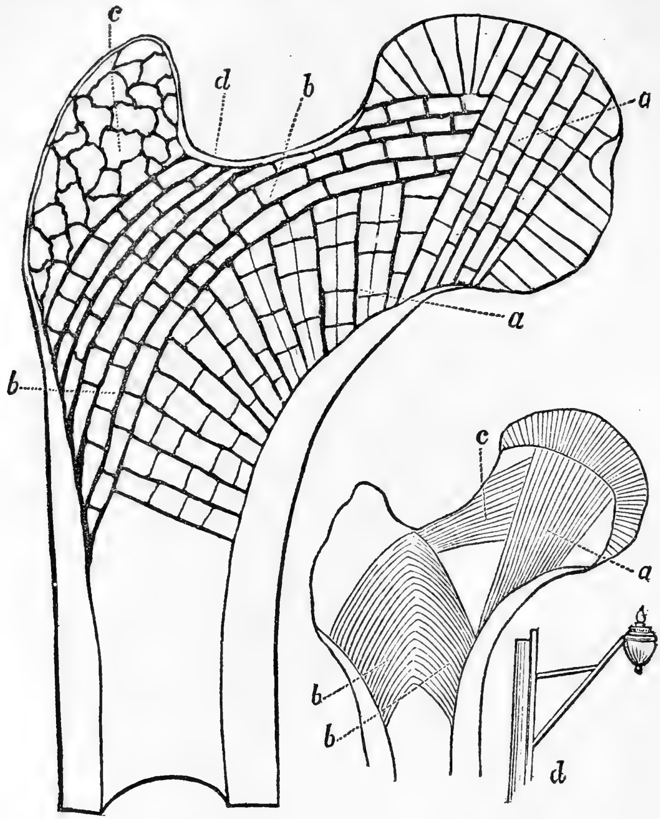


Fig. 30. Fig. 31.

to that portion of the preceding class of fibres which supports the upper surface of the head, as well as to the shell of bone between it and the

trochanter at (*d*). Both of these series are braced by other fibres, which are arranged at right angles to their direction. The cancelli of the great trochanter at (*c*) have no determinate form.

If this description be correct, the "archwork" described by Mr. Ward does not exist, nor the more complex arrangement described by Bourgery and Jacob. In fact, an arch which should be made to resist force in this direction would not be used in accordance with recognized architectural rules. An arch is usually made to resist or sustain pressure in lines perpendicular to its surface; but is not adapted for opposing lateral traction.

The upper series of fibres will get their points of resistance on the wall of bone below the trochanter, and not on the supposed archwork. The curved fibres (*b b*) will resist in virtue of their tenacity, and the straight or radiating series (*a a*) in virtue of their rigidity. One resists and is adapted to resist pressure, and the other resists and is equally adapted to resist traction.

We can appreciate the effect which force applied to the head of the femur would have upon its shell and cancelli, by calling to mind what takes place in a cylinder or tube when an attempt is made to bend it. If it be but slightly elastic, it will become more or less flattened or collapsed on the side toward which it is bent; if sufficient

force be applied, when it yields it will bend into an angle on the concave side, but the convex side still retaining its curve. The tenacity of the material being greater than its rigidity, it yields to pressure rather than tension, the concave side of the tube being compressed, while the convex stretches. The same effect will be still better seen in bending the branch of a tree, when the bark, if it yield on the convex side, will be torn asunder, whereas on the concave side it is thrown into folds. The shell of the neck of the thigh may be regarded as a bent tube, and is adapted to resist pressure by its oval form, the longest axis being vertical; and secondly, by the greater thickness of the concave side of the neck, to which the weight is more directly transmitted, and which in consequence of its curved form is more likely to yield to compression than the convex surface on the opposite side to traction.

The walls of the bone are still further supported by the disposition of the cancelli, which act as so many braces within. In addition to this, however, these last form a segment of an arch, and themselves support directly a portion of the weight of the body, and transmit it to the walls of the neck. If, on the application of weight to the head of the bone, the neck yield at all, the effect will be tension of the fibres (*b b*); and in consequence of their resting beneath upon the fibres (*a a*), compression of these last.

It is worthy of notice in connection with these directions of force, that the radiating series (*a a*), which support pressure by their rigidity, are the strongest, and the series at right angles and between them, which serve as braces, are more slender; while the curved series (*b b*), which resist by their tenacity, are the strongest, and the braces, which may be regarded as a continuation of the radiating series, are the weakest; precisely as would be the case in the frame of a building: the braces of the circular series become stronger as you approach the centre of the bone where the pressure becomes the greatest.

The shell of the neck is of itself sufficient to support great weight, in virtue of its form and structure; but its power of resistance is still farther increased by the cancelli, which form within a light truss or framed arch; the long fibres at (*a*) transfer weight directly to the under side of the neck. They, as well as the shell of the neck at (*d*), are supported by the curved fibres (*b b*), and these in turn by the radiating fibres (*a*). The whole may be regarded as equivalent to an increased thickness of those portions of the shell of bone above and below, which are the seats of the greatest strain and pressure.

The weight of the body is transmitted through the shaft of the femur to the condyles below, the space between these sustaining but little pressure.

III. THIGH

The lower portion of the thigh has only a thin shell, but here its diameter is largest and filled with the cancellated structure, which especially in the lateral portions has a very definite arrangement; the cancelli forming a series of pillars, which ascend very nearly vertically from the surfaces of the condyle to the walls of the bone above them, which are bent inwards as the bone diminishes its diameter towards the middle of the shaft. A corresponding arrangement exists in the two extremities of the tibia, where the surface which is the seat of pressure is sustained by columns of bony fibres extending to the walls above or below it, according as the upper or lower portion of the bone is examined. This structure has been distinctly figured and described by Bourgery and Jacob.[1] The cancelli are, as in the parts before described, prevented from lateral flexion by braces which are interposed at right angles to their direction.

IV. ASTRAGALUS

The tibia alone bearing vertically on the astragalus, this last bone will necessarily sustain in each foot one half the weight of the body, or the whole of it when it is supported on one foot.

[1] Op. cit., Tome I. pp. 119 and 121, also Pl. 43, Figs. 3, 4, and 7.

When the small size of the surface on which the tibia rests is borne in mind, it will be readily anticipated that in its internal structure it will give us another illustration of mechanical adaptation. The astragalus, though it receive so many shocks in the violent movements of the body and is called upon to resist so much vertical force, is nevertheless a light bone and presents areolæ in its interior of large size. The astragalus rests below on the os calcis, by means of two articulating surfaces of different sizes, and in front on the scaphoid bone, so that whatever pressure is transmitted to it is in turn transferred to the surfaces of the bones just named, with which it is in contact. The pressure is therefore transmitted in two directions, but as the astragalus, by means of its greater articulating surfaces, rests mainly on the os calcis, the larger amount is transferred in the direction of this bone.

On making a longitudinal section of this bone (*Fig.* 32), two series of cancelli are distinguishable at sight — one, a nearly vertical series (*a*), one end of which sustains the arched portion of the astragalus on which the tibia bears, and the other rests on the surface beneath, which articulates with the os calcis; the second (*b*), a horizontal series nearly at right angles to the preceding, one end of which rests on the vertical series and the other on the surface articulating with the sca-

phoid bone. In the angle formed by these two series is a third (*c*), much less regular, the direction of which is not well defined, but has a general tendency downwards and forwards towards

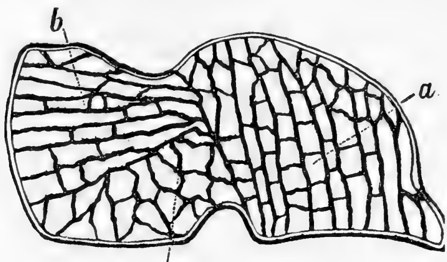


Fig. 32.

the anterior and inferior articulating surfaces of the bone. This portion sustains no direct pressure.

V. OS CALCIS

It is through this bone that the weight is at last transmitted to the ground, and this takes place in two different directions: one directly through the tuberosity of the heel, and the other indirectly through that surface which articulates with the cuboid bone, and this in turn with the 4th and 5th toes. The os calcis, however, does not simply form a basis of support; it is at the same time one of the arms of a lever by which the body is raised from the ground under the influence of great muscular action. The whole

foot forms an arch, one end of which springs from the ground in the os calcis, and the other from "the ball of the foot" or the ends of the metatarsal bones. The arch is formed by the metatarsal and tarsal bones, the centre of which corresponds with a line passing transversely through the scaphoid and cuboid bones. By reference to the skeleton, it will be seen that the surface of the astragalus, on which the tibia rests, and the surfaces of the os calcis, which support the astragalus, are behind this centre of the arch; consequently, the weight of the body will be thrown more upon the os calcis than upon

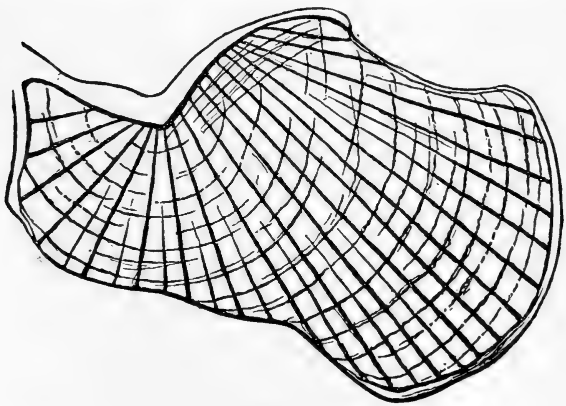


Fig. 33.

the metatarsal bones. A section through this bone (*Fig.* 33) gives two series of cancelli, one radiating from the upper surface towards the two surfaces on which the bone rests, and more spar-

ingly to the intervening portions; a second series at right angles to the last and which, as the former radiate from a common centre, will necessarily assume a curved direction. By far the largest portion of the first are directed towards the tuberosity of the heel, which serves the double purpose of a base and lever. That portion which is just beneath the articulating surface, and which does not come within the range of either of the surfaces of support, may be regarded as forming an inverted arch.

The os calcis of man contrasts with that of other animals, not only in its size and relation to the rest of the foot, but in its minute and internal arrangement, so that the assertion made by Mr. Lawrence many years ago, independently of its structure within, that "*ex calce hominem*" would be a safer rule than "*ex pede Herculem*," gains additional force.[1]

In the above descriptions the minute structure of several bones has been described as well as the nature of the force which they are intended to resist. It is not always safe to attempt to assign the final cause of animal structures, to indicate the intention of nature in certain conditions of things — though there can be no risk in describing in connection such conditions of organization

[1] *Lectures on Physiology, Zoölogy, and the Nat. Hist. of Man,* p. 124. London, 1822.

as co-exist.[1] As to the individual bones, it has been shown in what direction force or weight is applied to them, and in what direction the cancelli are arranged within them. On the lumbar vertebræ there is vertical pressure; within, the principal fibres are also vertical. On the neck of the thigh-bone the weight of the body is applied obliquely to the end of an arm; within it there is a combination of fibres, giving strength with lightness, which forms a frame mechanically adapted for resisting the weight which rests upon it. On the astragalus the pressure again is vertical, but this bone rests on two others, one below it, the os calcis, and the other in front, the scaphoides; within there exists two series of cancelli directing the pressure on the surfaces of support, and very nearly the same description applies to the os calcis. A certain direction of fibres in all these instances co-exists with a certain direction, or certain directions, of the transmission of pressure. From this constant association of structure and function, the inference seems unavoidable, that they are means and ends.

The next subject for consideration is, as to the existence of some more general condition to which

[1] "Whatever may become of hypothesis, the man who has made a permanent addition to the knowledge of facts has rendered an imperishable service to science." — GEORGES CUVIER, *Anatomie Comparée.*

these individual instances are subservient — and this involves the necessity of inquiring, to what extent similar structures exist in other members of the Mammiferous series? After having made numerous sections of the corresponding bones of other animals, scarcely any indications of these peculiar arrangements of the cancelli have been demonstrated. The columnar arrangement of the bony fibres of the vertebræ seems the most common. As a general rule, the strength of the bone seems to be obtained in other mammals at the expense of its lightness, by giving greater thickness and density to the outer shell, as well as by stouter cancelli with smaller areolæ. The peculiar structure of the neck of the thigh, and of the astragalus, seems to exist in man alone. The only animals in which I have detected any approach to the structure of the neck of the thigh in man are in the two species of anthropoid African apes, the Chimpanzee (*Troglodytes niger*), and the Engé-ena (*T. gorilla*), the two species which stand at the head of the brute creation, and which of all brutes make the nearest approximation to the erect attitude. In these, slight traces of the truss-work described in man exist, but in them as in other animals the shell of the neck is much stouter and thicker.

The structures which have been described in this communication are found mainly, if not

solely, in the bones connected directly with locomotion. And as they exist in man alone, or certainly present in him the highest degree of perfection, we cannot escape the conviction that they relate to the kind of locomotion which he alone of the whole animal series can be said to possess, namely, that of walking erect, and which requires in the passive and resisting organs subservient to it, in order that it may be effected with ease and grace, a nice combination of lightness with strength in the materials. His attitude more than any other, in consequence of the pillars of support being arranged in vertical planes, requires the most effectual means for counteracting shocks; for in all other mammals the points of support are usually four, and at the same time the bones of the legs make angles more or less acute with each other, and therefore are in a condition to yield readily by flexion to any increased force; and this is true of all birds and reptiles. In the elephant, the thighbones are vertical, but they are nearly at right angles with the vertebral column, and the pillars of support are four instead of two.

From the considerations which have now been offered, it is believed that the two propositions which were stated at the commencement of the article have been sustained, and that if any additional facts were necessary to show that the human skeleton deviates widely in the details of its struc-

ture from that of all brutes, even the most anthropoid, we should have a characteristic sign in the arrangement of the cancelli of such of his bones as play the most important part in sustaining and moving his body.

Jeffries Wyman, Del.

SEARCHING INDIAN SHELL HEAPS IN MAINE.

LIST OF SCIENTIFIC PAPERS AND WORKS BY JEFFRIES WYMAN

1. On the indistinctness of images formed by oblique vision. Boston Medical and Surgical Journal, Sept. 1837.

2. On fossil bones from Georgia and Burmah and a recent elephant's tooth from Singapore. Amer. Journ. Sci., xxxvi. 1839, pp. 385–386.

3. Note on a collection of fossil bones from Athens. Amer. Journ. Sci., July, 1839; Proc. Bost. Soc. Nat. Hist., 1839.

4. Remarks on the worms in measly pork. Amer. Journ. Sci., July, 1839; Proc. Bost. Soc. Nat. Hist., 1839.

5. Remarks on a bat, *Molossus ater*, etc., from Surinam. Amer. Journ. Sci., July, 1839. Proc. Bost. Soc. Nat. Hist., 1839.

6. Notice of the tooth of a mastodon. Amer. Jour. Sci., xxxix. 1840, pp. 53–54.

7. On the anatomy of *Tebennophorus carolinensis*. Boston, Proc. Nat. Hist. Soc., i. 1841–44, pp. 154–155; Boston Journ. Nat. Hist., iv. 1843–44, pp. 410–415.

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9. On a species of Filaria in the lungs of a sheep. Proc. Bost. Soc. Nat. Hist. [1840.] Amer. Journ. Sci., xxxix. p. 183. Oct. 1840.

10. Report on *Nautilus umbilicatus*. Proc. Bost. Soc. Nat. Hist. [Feb. 19, 1840.] Amer. Jour. Sci., xxxix. p. 185. Oct. 1840.

11. On buried wood, Unio, etc., in river sand at Lowell. Proc. Bost. Soc. Nat. Hist. [July 15, 1840.] Amer. Journ. Sci., xl. p. 388. March, 1841.

12. Note on the cranium of a seal (*Stenorhynchus leptonyx*) from the South Pacific. Proc. Bost. Soc. Nat. Hist. [Jan. 20, 1841.] Amer. Journ. Sci., xl. p. 390. March, 1841.

13. Notice of the howling monkey (*Simia seniculus*). Amer. Journ. Sci., xl. 1841, pp. 387–388.

14. On the anal pouches of the skunk (*Mephitis Americana*). Boston, Proc. Nat. Hist. Soc., i. 1841–44, p. 110.

15. On the sternum of a male trumpeter swan (*Cygnus buccinator*). Boston, Proc. Nat. Hist. Soc., i. 1841–44, p. 119.

16. On the microscopic structure of the teeth of the Lepidosteus and their analogies with those of the labyrinthodonts (with a plate). Boston, Proc. Nat. Hist. Soc., i. 1841–44, pp. 131–132; Amer. Journ. Sci., xlv. 1843, pp. 359–363; London Physiol. Journ., 1843–44 (?).

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18. Notice of the Zoölogy of New York. By J. E. DeKay. Amer. Journ. Sci., xlv. pp. 397–399. Sept. 1843.

19. Notice of Agassiz's Monographies and Echinodermes vivans et fossiles. Amer. Journ. Sci., xlv. pp. 399–400. Sept. 1843.

20. On the anatomical structure of *Glandina truncata*, Say. Boston, Proc. Nat. Hist. Soc., i. 1841–44, pp. 154–155; Boston Journ. Nat. Hist., iv. 1843–44, pp. 416–421.

21. Description of a blind fish from a cave in Kentucky. Amer. Jour. Sci., xlv. 1843, pp. 94–96.

22. (With Thomas S. Savage.) Observations on the external characters, habits, and organization of the *Troglodytes niger*, Geof. Boston Journ. Nat. Hist., iv. 1843–44, pp. 362–376, 377–386.

23. On *Echinorhynchus nodosus.* Proc. Bost. Soc. Nat. Hist. Jan. 4, 1843.

24. On a Rotifer and Tardigrades. Proc. Bost. Soc. Nat. Hist. Feb. 1, 1843.

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26. Ascarides from Cyclopterus. March 1, 1843.

27. Description of a new species of torpedo. Proc. Amer. Acad. Arts and Sci. April 25, 1843.

28. Annual address as president of the Boston Society of Natural History. May 17, 1843.

29. On *Spongia fluviatilis.* Proc. Bost. Soc. Nat. Hist. Sept. 4, 1844.

30. (With Thomas S. Savage.) Notice of the external characters, habits, and osteology of *Troglodytes gorilla,* a new species of ourang from the Gaboon River. Boston Journ. Nat. Hist., v. 1845–47, pp. 417–422; Ann. Sci. Nat., xvi. (Zool.), 1851, pp. 176–182; Boston, Proc. Nat. Hist. Soc., ii. 1845–48, pp. 245–248; Amer. Journ. Sci., viii. 1849, pp. 141–142.

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32. *Linguatula armillata* and *L. clavata.* Boston, Proc. Nat. Hist. Soc., ii. 1845–48, p. 59; Boston, Journ. Nat. Hist., v. 1845, pp. 255–296.

33. On the fossil skeleton recently exhibited in New York as that of a sea-serpent under the name of Hydrarchos Sillimani. Boston, Proc. Nat. Hist. Soc., ii. 1845–48, pp. 65–68.

34. On the fossil cranium and lower jaw of an extinct rodent. Boston, Proc. Nat. Hist. Soc., ii. 1845–48, pp. 138–139.

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